A CARBONIZATION PLANT FOR THE TREATMENT OF SUBBITUMINOUS COALS

by

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Research Council of Alberta
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Edmonton, Alberta April, 1948.

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A THESIS

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PREFACE AND ACKNOWLEDGMENTS

The investigation described in this thesis was carried out in accordance with a general program of research of the Research Council of Alberta under the successive supervision of Mr. E. Stansfield, Mr. W.A. Lang and Mr. A. McCulloch.

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T A B L E S

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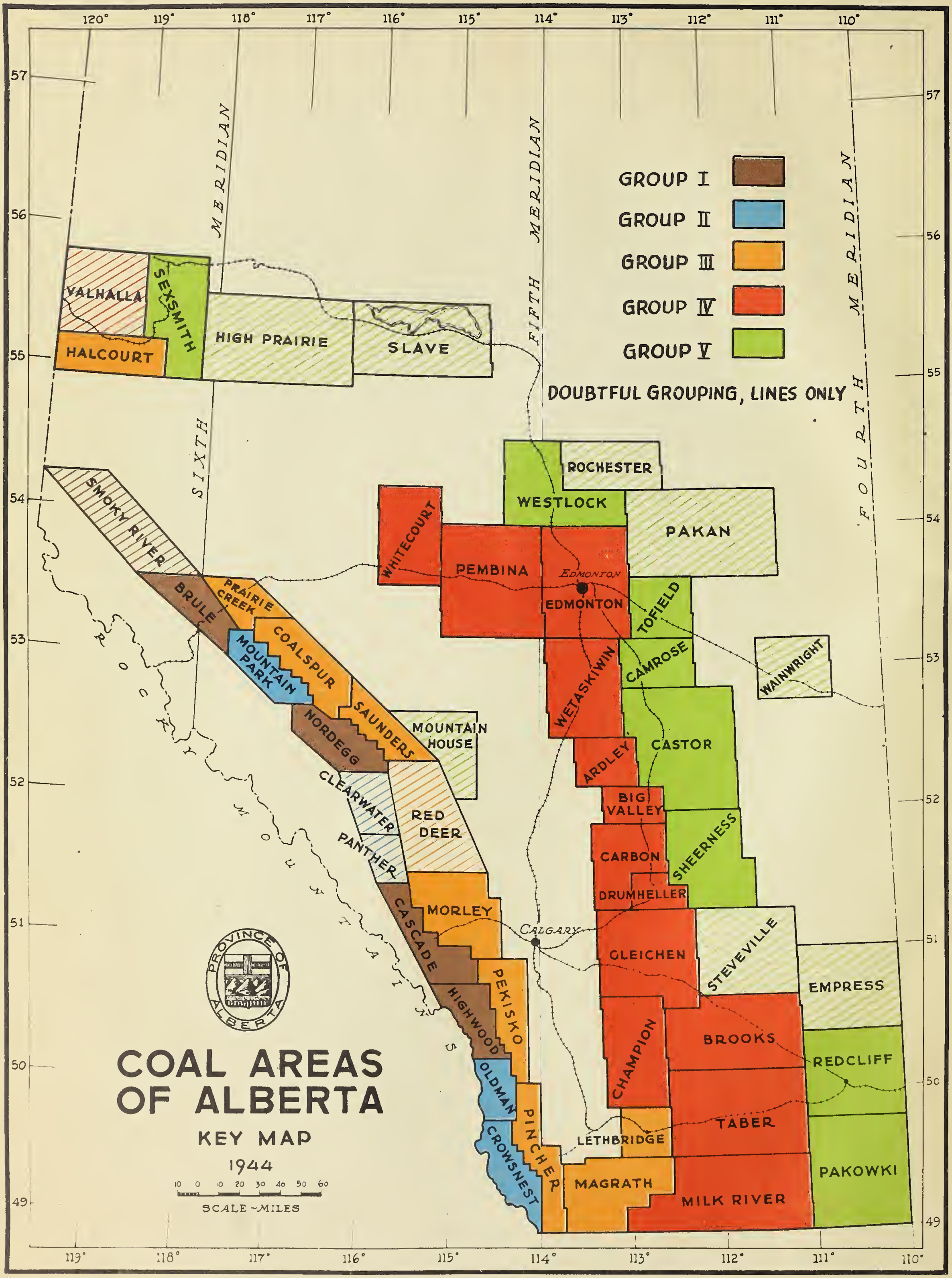
FIGURES - (Continued)



COAL AREAS OF ALBERTA
KEY MAP
1944
SCALE - MILES
GROUP I
GROUP II
GROUP III
GROUP IV
GROUP V
DOUBTFUL GROUPING, LINES ONLY
SIXTH MERIDIAN
FIFTH MERIDIAN
FOURTH MERIDIAN
ROCKY MOUNTAINS
PROVINCE OF ALBERTA
VALHALLA
SEXSMITH
HALCOURT
HIGH PRAIRIE
SLAVE
ROCHESTER
WESTLOCK
PAKAN
WHITECOURT
PEMBINA
EDMONTON
TOFIELD
WAINWRIGHT
CAMROSE
WETASKIWIN
CASTOR
ARDLEY
BIG VALLEY
SHEERNESS
CARBON
DRUMHELLER
GLEICHEN
STEVEVILLE
EMPRESS
CHAMPION
BROOKS
REDCLIFF
TABER
LETHBRIDGE
MAGRATH
MILK RIVER
PAKOWKI
SMOKY RIVER
BRULE
PRAIRIE CREEK
MOUNTAIN PARK
COALSPUR
NORDEGG
SAUNDERS
MOUNTAIN HOUSE
CLEARWATER
RED DEER
PANTHER
MORLEY
CASCADE
CALGARY
PEKISKO
HIGHWOOD
OLDMAN
CROWSNEST
PINCHER

PLATE I

I. INTRODUCTION

This thesis deals with the development, in the laboratories of the Research Council of Alberta, of a low-temperature-carbonization plant for the treatment of Alberta subbituminous coals to produce a char which can be briquetted to give, relatively to the coal used, a high-grade solid fuel suitable for transport to and marketing in Eastern Canada.

A. Nature of Coals in the Province of Alberta.

Coal-bearing beds in Alberta occur in three different geological formations namely, the Edmonton, the Belly River, and the Blairmore-Kootenay. (1) The first two formations are of Upper Cretaceous and the third of Lower Cretaceous age. The Blairmore-Kootenay coals of Lower Cretaceous age are more mature than the Belly River or Edmonton coals of Upper Cretaceous age. The degree of maturity, however, appears to have been dependent more on the pressure to which the coal beds have been subjected than upon the geological age of the deposits. Speaking generally, the rank of Alberta coals increases from east to west, that is, from the plains to the foothills and mountains, the mountain building forces which resulted in the formation of the Rocky Mountain barrier apparently being the effective agents in the maturing of the coals.

The Research Council of Alberta has divided the Province into districts known as coal areas. These are shown in a key map on Plate I. The coals of Alberta are also divided for convenience into five broad groups, each containing coals of the same general character and used for the same purposes. These groupings are also shown on Plate I. The characteristics, occurrence and analyses of the coals of the different groupings are given below. (1)

Group I - Low volatile, non-coking coal from mountain areas; commonly called steam coal.

Coals of this type have good storage properties, resisting weathering and burn with a short, slightly smoky flame. These coals are used for railways and for steam raising in general. When briquetted they find a market for domestic heating.

Important areas where this type of coal is mined are Cascade, Highwood and Nordegg.

Group II - High Volatile, coking bituminous coal from mountain areas; also commonly called steam coal.

This class of coal has also good storage properties, is weather-resisting but burns with a medium to long, smoky flame. Coals of this class are used for railways and for steam raising in general, for the manufacture of coke, as smithy coal, and in the manufacture of cement.

Group III - High volatile, non-coking coal, principally from foothills areas, with good storage and weather-resistant properties. Coals of this type are non-coking and burn freely with a long, slightly smoky flame. They are for domestic and for steam raising purposes. In general, they withstand handling and transport well and can be shipped and stored satisfactorily for a considerable period without marked deterioration to size and properties.

Important areas in which coals of this group are mined are Coalspur, Lethbridge, Prairie Creek and Saunders.

Group IV - A so-called domestic coal with fair storage properties mined in prairie areas.

With care, this class of coal can be stored under

cover. It is a free-burning, non-coking type which ignites easily and burns with a long, smokeless flame. The principal uses are for domestic heating and steam raising. It can be shipped in box cars without undue breakage.

Important areas in which coals in this group are mined are Carbon, Drumheller, Edmonton, Pembina and Taber.

Group V - A so-called domestic coal with poor storage properties mined in prairie areas.

This class of coal will not store well. It is a free-burning, non-coking type of coal, igniting easily and burning with a long smokeless flame. As with coals in Group IV the principal uses are for domestic heating and steam raising.

Important areas in which coals within this group are mined are Camrose, Castor, Sheerness and Tofield.

Table I gives typical analysis for the various groups of coals enumerated but it must be understood that since each group comprises a wide range of coals the analysis given for any one group is merely typical. The analysis of a particular coal within one group may thus differ somewhat from the analysis given below as representative of that group.

Table I

Proximate Analysis and Calorific Value of Coals
of Various Groups

Basis: Coal as Mined

	Group I	Group II	Group III	Group IV	Group V
Moisture, per cent.	1 1/2	1 1/2	10	19	27
Ash, per cent.	8 1/2	12 1/2	10	7	7
Volatile Matter, per cent.	15	25	34	30	28
Fixed Carbon, per cent.	75	61	46	44	38
Heat Value, B.t.u. per lb.	14,000	13,200	10,900	9,700	8,300

B. Classification of Alberta Coals

Since 1938, coal in Canada has been classified according to the system used by the American Society for Testing Materials. This classification seeks to define broadly the stage in the metamorphosis of the original plant material from lignite towards anthracite. This stage is known as rank, the less mature coals being termed low rank coals and the more mature coals high rank coals.

In the classification according to rank, as shown in Table II (1) high rank coals are characterized primarily by the percentage of fixed carbon in the dry, mineral-matter free coal; whilst lower rank coals are characterized by the heat value of the moist, mineral-matter-free coal, that is to say with coal containing that amount of moisture which the mineral-matter-free coal might be considered to contain in the seam. Secondary distinctions are made according as

to whether the coal is agglomerating, that is forms a firm button of coke when the coal is carbonized under standard conditions as in the volatile matter test, and according as to whether the coal is weather resistant as indicated by the extent of its disintegration in an accelerated weathering test.

Table II

Classification of Coals by Rank

Class	Group	Limits of Fixed Carbon or B.t.u. Mineral Matter-Free Basis	Requisite Physical Properties
I. Anthracitic	1. Meta-anthracite	Dry F.C. 98% or more	
	2. Anthracite	Dry F.C. 92% or more & less than 98%	
	3. Semianthracite	Dry F.C. 86% or more & less than 93%	Non-Agglomerating [1]
II. Bituminous [3]	1. Low volatile bituminous coal	Dry F.C. 78% or more & less than 86%	
	2. Medium volatile Bituminous coal	Dry F.C. 69% or more & less than 78%	
	3. High volatile A bituminous coal	Dry F.C. less than 69% & moist [2] B.t.u. 14,000 [4] or more	
	4. High volatile B bituminous coal	Moist [2] B.t.u. 13,000 or more & less than 14,000	
	5. High volatile C	Moist B.t.u. 11,000 or more & less than 13,000 [4]	Either agglomerating or non-weathering [5]
III. Subbituminous	1. Subbituminous A coal	Moist B.t.u. 11,000 or more & less than 13,000 [4]	Both weathering & non-agglomerating
	2. Subbituminous B coal	Moist B.t.u. 9,500 or more & less than 11,000 [4]	
	3. Subbituminous C coal	Moist B.t.u. 8,300 or more & less than 9,500 [4]	
IV. Lignite	1. Lignite	Moist B.t.u. less than 8,300	Consolidated
	2. Brown coal	Moist B.t.u. less than 8,300	Unconsolidated

1. If agglomerating, classify in low volatile group of bituminous class.

2. Moist B.t.u. refers to coal containing its natural bed moisture but not including visible water on the surface of coal.

3. It is recognized that there may be non-coking varieties in each group of the bituminous class.

4. Coals having 69 per cent. or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of B.t.u.

5. There are three varieties of coal in the high volatile C bituminous coal group, namely,
   Variety 1, agglomerating and non-weathering
   Variety 2, agglomerating and weathering
   Variety 3, non-agglomerating and non-weathering

In addition to the A.S.T.M. classification and the five groupings enumerated a system of classification according to common usage has been adopted in Alberta.(2) Table III gives all three methods of subdivision and indicates the extent to which they agree, disagree and overlap.

Table III

Classification and Grouping of Alberta Coals

Alberta Classification of common usage and of Mines Branch Statistics*	Canadian Classification (A.S.T.M. D 388-38)	Alberta Research Council Grouping
	Class	
	Anthracitic (1) Meta-anthracite	
Anthracite	(2) Anthracite	
	(3) Semi-anthracite	
		Group I
	Bituminous	
	(1) Low volatile bituminous coal	
Bituminous	(2) Medium volatile bituminous coal	Group II
	(3) High volatile A bituminous coal	
Subbituminous	(4) High volatile B bituminous coal	Group III
	(5) High volatile C bituminous coal	
Domestic	Subbituminous	
	(1) Subbituminous A coal	Group IV
	(2) Subbituminous B coal	
	(3) Subbituminous C coal	Group V
	Lignite (1) Lignite	
	(2) Brown coal	

* This classification appears to have been considerably modified commencing about 1934, when apparently, it was decided that none of the coals was truly anthracite. Since 1945 coal formerly termed domestic has been returned as subbituminous.

C. Occurrence and Resources of Alberta Coals

Alberta's coal reserves and production in 1943, according to the above five groupings, have been given as follows: (2)

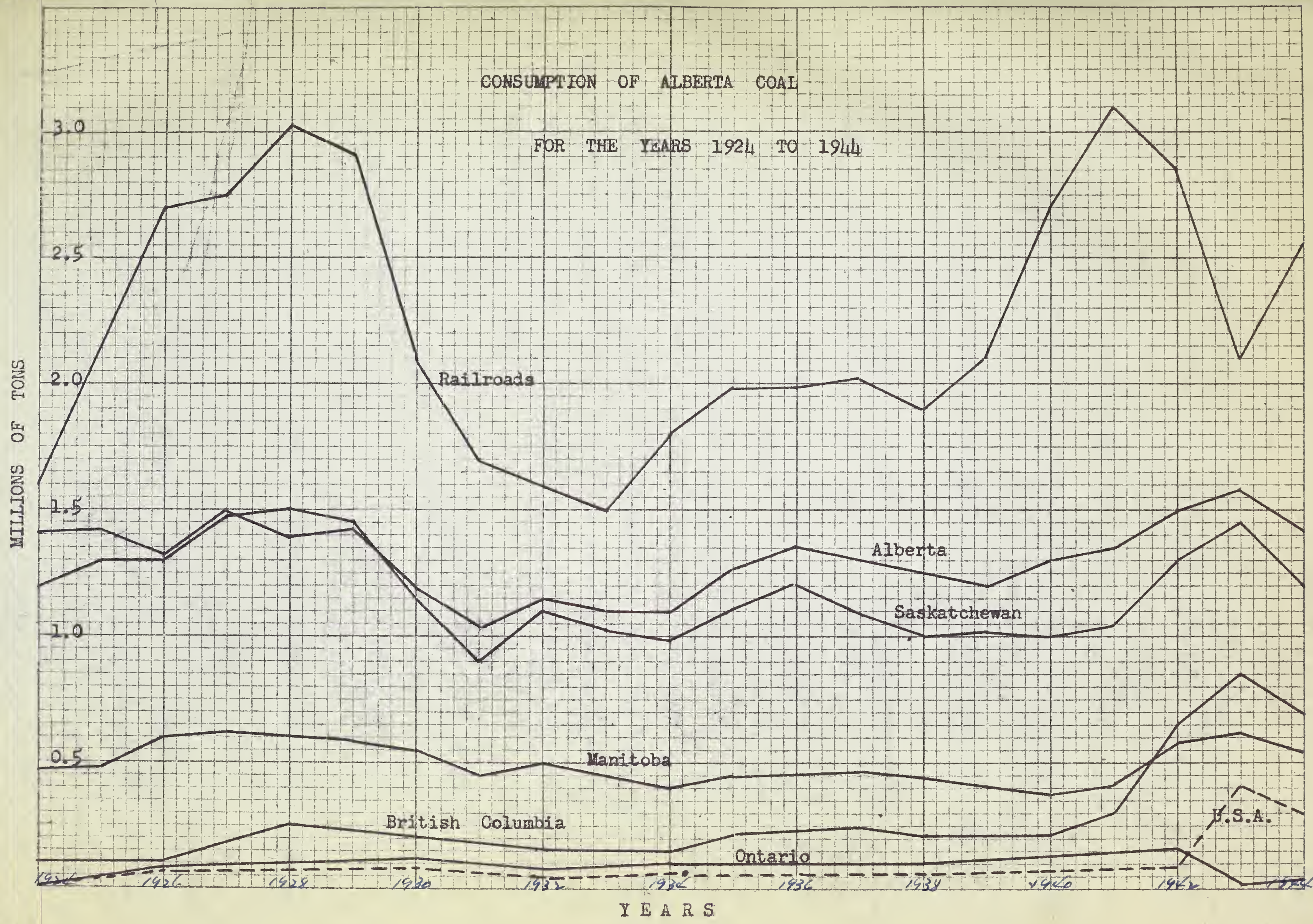
Table IV

		Coal Reserves Millions of Tons	Production in 1943 Thousands of Tons
Group I	5 areas	16,100	996
Group II	5 areas	13,600	2486
Group III	10 areas	10,200	1359
Group IV	14 areas	5,340	2533
Group V	16 areas	1,320	304

D. Consumption of Alberta Coal

The consumption of Alberta coal for the period 1924 to 1944 inclusive is shown in Figure I. (2) The railways, utilizing bituminous coals are by far the largest consumers. Consumption of Alberta coal within the Province, except for the period 1929 to 1940, the depression years, has remained in the neighborhood of 1.5 million tons per annum. Saskatchewan has consumed about an equal amount of Alberta coal but during the past few years the curve for Saskatchewan consumption has fallen away from that for Alberta and will probably continue to do so as the production in Saskatchewan increases. For the past 20 years, Manitoba's consumption of Alberta coal has fluctuated slightly but generally speaking it is about one-half million tons per annum. Consumption will probably not change

FIGURE I



CONSUMPTION OF ALBERTA COAL
FOR THE YEARS 1924 TO 1944
MILLIONS OF TONS
3.0
2.5
2.0
1.5
1.0
0.5
Railroads
Alberta
Saskatchewan
Manitoba
British Columbia
Ontario
U.S.A.
1924
1926
1928
1930
1932
1934
1936
1938
1940
1942
1944
YEARS

appreciably unless there is some unforeseen alteration of conditions in the Province. The curve for the consumption of Alberta coal by British Columbia rose rapidly after the outbreak of war. During the war period, coal distribution was centrally directed and western supplies of coal for eastern markets were directed to markets in the west. After a period of post war adjustment, consumption by British Columbia may be expected to rise.

Ontario showed a small but steadily-increasing consumption of Alberta coal until 1942 and consumption would undoubtedly have increased still further but for the re-direction of shipments ordered in 1943 as a war measure. Because of its large population and the relatively high concentration of industry in Ontario, consumption in this Province of both industrial and domestic coal is very substantial. Over half of Ontario's requirements, however, amounting in 1941 to more than 14 million tons is imported from the United States.

Ontario, therefore, is potentially the largest market for Alberta coals. Considered broadly, the industrial needs of Ontario can be met by the supply of bituminous coals whereas domestic needs might reasonably be satisfied with supply of subbituminous coal or of solid fuels manufactured from them.

The investigation to be described in this thesis is concerned with the production from Alberta subbituminous coals of a solid fuel which would meet the requirements of the domestic coal market in Ontario in particular and Eastern Canada in general.

E. <u>Occurrence and Resources of Alberta Subbituminous Coals</u>

T he subbituminous and lignitic coals of Groups IV and V occur in 30 of the 50 coal areas already named. From Table IV it will be seen that these areas are responsible for 37% of the total coal production of the province.

These coal areas lie as a band through the middle of the province as is shown in Plate I. The largest producing centres are Drumheller, Edmonton and Tofield; the Lethbridge area is excluded because the coals in this field are in general more mature than those mentioned in the former areas.

Although the known reserves of bituminous coals are much larger than those of the subbituminous and lignitic types, production of bituminous coals in mountainous regions is limited to those areas which are serviced by railroads. This perhaps is one of the main reasons why the coal production in the subbituminous areas as a percentage of the total reserves in these areas is greater than the comparable figure for the mountain regions. The prairie coal seams in the regions lie under relatively shallow cover and in contrast with the sharply folding and steeply pitching seams in the mountain regions, they occur in beds which have not been greatly disturbed. In certain areas the seams may be worked by open-strip mining, but elsewhere the seams are worked from portals or shallow shafts or by means of fairly gentle inclines.

F. Characteristics of Subbituminous Coals (3)

The subbituminous coals are characterized by the following properties:

1. As they occur naturally they contain a large amount of water. The moisture varies from about 12.7 per cent. in the Champion Area to about 29.6 per cent. in the Sexsmith Area. On losing moisture by air-drying the coals usually disintegrate, either crumbling to a powder or developing well-marked, laminar cracks.
2. They are non-coking.
3. In general, the ash fuses at a relatively low temperature.
4. On the dry, ash-free basis, they contain more oxygen and less carbon than any of the bituminous coals.
5. Their high oxygen and moisture contents, which of course infer low calorific values, account for the relatively low flame temperatures and calorific intensities which will be developed when these coals are burned.
6. Some typical analyses are:

Table V

Typical Analyses of Some Alberta Subbituminous Coals (1)

Basis:- Coal as Mined

Area	Moisture Per cent.	V.M. Per Cent.	Ash Per Cent.	Calorific Value
				B.t.u./lb
Drumheller	18.9	30.7	6.8	9,700
Edmonton	24.5	28.5	6.6	8,890
Tofield	28.3	28.0	6.5	8,300

G. Economic Factors Affecting the Marketing and Utilization of Alberta Subbituminous Coals in Eastern Canada.

A number of economic factors are involved in the marketing of the subbituminous coals of Alberta in Eastern Canada.

Since 1933, the freight rate for Alberta coal from any place in Alberta to all points in Ontario has been set at the flat rate of $8.00 per ton. (2) The Dominion Government contributes a flat subvention rate of $2.50 per ton so that a net freight rate of $5.50 per ton has to be provided for in marketing.

The $2.50 per ton subvention rate is not a long term arrangement but is renewed yearly and can be withdrawn by the Dominion Government at any time. This situation has naturally a very detrimental effect on the movement of western coal to Ontario. The coal dealers in Ontario hesitate to discontinue relations with American coal operators with a view to handling Alberta coal in case the subvention is withdrawn. For the same reason the operators of Western Canada are reluctant to promote sales by extensive advertising of their products in Ontario.

In the case of coals imported from the United States, the distances encountered are much shorter and here the freight rate varies with the length of haulage. The lowest price for American coals occurs at the cities on the north shore of the Great Lakes. Inland areas, however, must bear the added cost of railway shipping charges.

The following table gives a comparison of the prices of Drumheller Furnace Lump coal with two types of American coals in various Ontario cities.

Table VI

Comparison of Prices of Some Coals in Various Ontario Markets in 1939-40 (2)

Kind of Coal	Toronto	Peterborough	Timmins
American Anthracite	$15.50	$16.75	$20.75
Pocahontas Coal	13.00	13.50	18.25
Alberta Drumheller Furnace Lump	13.15	13.15	14.00*

* The higher cost of Alberta coal in Timmins is due to a larger profit margin to the dealers in that city.

It will be seen that the price of Drumheller coal in Toronto was $2.35 less than the price of U.S. Anthracite and 15¢ more than the price of Pocahontas coal. The margin increases in favor of Alberta coal as the distance inland from Toronto increases. The price of Drumheller furnace lump coal at the mine in 1943 was $4.65 per ton. With a net freight rate of $5.50 and a dealers gross margin of $3.00 the price of this coal to the consumer came to $13.15.

From a competitive standpoint it is also necessary to compare the analyses of the imported American coal and Alberta Domestic coal. Table VII gives a comparison of the proximate analysis, the calorific values and the price per therm of these coals.

Table VII

Comparison of Proximate Analysis, Calorific Value (4) and Price per Therm of U.S. and Alberta Subbituminous Coals in Ontario Cities

	Moisture per cent	Volatile Matter per cent	Ash per cent	Calorific Value B.t.u./ lb.	Toronto price per therm	Timmins price per therm
Pennsylvania (anthracite)	3.9	---	11.1	12,780	6.1¢	8.1
Pocahontas (Semi-bituminous)	Dry	18.6	6.1	14,750	4.4	6.2
Drumheller	18.9	30.7	6.8	9,700	6.8	7.2
Edmonton	24.5	28.5	6.6	8,890	7.4	7.9
Tofield	28.3	28.0	6.5	8,300	7.9	8.4

It must, however, be pointed out that the price per therm is not necessarily an exclusive measure of value. In fact, it is a minor issue with the average householder. The features sought for in a domestic fuel are, in general, a minimum of smoke produced on burning, cleanliness in handling, low ash content and ease of initiation of combustion. The Alberta subbituminous coals have these features and it is for these reasons that for domestic heating they may be preferred to both Alberta and American bituminous coals.

However, in spite of these merits of Alberta subbituminous coals for domestic purposes, their high freight rates per therm and their poor storing and shipping properties present serious disadvantages to long distance shipping. This situation has led the Research Council of

Alberta to consider the possibility of converting these coals by carbonizing them and then briquetting the resultant char with a suitable binder into fuels of a convenient size, with good storage properties and having a more concentrated heat value.

It should be mentioned that a situation exists particularly in the Drumheller area which has an important bearing on the above situation. In that field about 14 per cent. of the total coal produced is in the form of slack coal, that is, generally speaking, below 3/8 - 3/4 inch mesh size. At present a certain amount of the slack coal is disposed of to various power plants. Should these power plants, however, convert their installations to gas firing the market for this class of material will become yet more restricted. The Alberta Subbituminous Coal Association indicated that the market for briquettes is very favorable.

II. History of the Development of Low Temperature Carbonization Processes for Treating Lignites

Certain of the so-called subbituminous coals occurring in the Upper Cretaceous formation of Alberta have been regarded by investigators elsewhere as well-matured, laminated, black lignites which may contain in the raw state up to 25 per cent. water. The large amounts of water in the raw coals greatly limits their value as fuels and common practice, especially in Germany, with coals of this kind has been to dry them by means of hot combustion gases, steam or even hot air and then to briquette the dried material or to use it directly for steam raising. The heat available in the dry lignites can be substantially increased further by moderate heat treatment of the coal up to a temperature of between 300° and 400° C.,at which temperature oils are first produced.

Investigations by Bone and his collaborators (3) on the heat treatment of coals of this kind shows that by heating up to a temperature of between 275° C. and 375° C. results in the removal not only of a considerable proportion of oxygen as steam but also of a very large amount of oxygen as carbon dioxide in the gases which are produced at these temperatures. It will be seen that the percentage of carbon dioxide in the gases evolved ranges from 70 to as much as 93 per cent. and that the weight of the gas is approximately four to seven per cent. of the coal substance.

It should be noted that these quantities refer to the dry coal substance exclusive of extractable matter in the form of wax, etc. The composition of the gases evolved up to this temperature, and at higher temperatures from coals of this kind are indicated in Table VIII.

Table VIII

Initial Decomposition of Brown Coals and Lignites

Coal	Oil Point °C	Weights evolved per 100 grams of dry dewaxed coal substance		Percentage carbon dioxide in gas evolved	Mol Ratio water to carbon dioxide expelled
		Gas	Steam		
Morwell Brown Coal	375	6.7	5.5	90.0	2.25
German Brown Coals					
Rhenish	260 300	4.9 6.1	5.0 4.0	93.2 91.4	2.6 1.7
Saxon	288 275	4.6 3.9	3.5 3.8	90.9 92.9	2.0 2.5
Saskatchewan Lignites	320 to 360	4.5	4.5	70 to 75	---

Upon further heating of the Dry Dewaxed Rhenish Brown Coals in a stepwise manner up to 800° C. the gases evolved are as shown in Table IX. The results are also shown in graph form in Figure II and as accumulated totals in Figure III.

Table IX

Gases Evolved From Rhenish Brown Coal in mls. at N.T.P. per 100 Gms. Dry Dewaxed Coal Substance

Temperature Range °C.	H_2S	CO_2	CO	C_nH_{2n}	CH_4 and C_nH_{2n+2}	H_2	N_2
up to 300°	Nil	2920	247	10	Nil	Nil	19
300 to 420	18	4272	860	235	767	Nil	38
420 to 500	10	1978	583	133	1890	496	24
500 to 600	3	1104	850	41	1395	1000	107
600 to 700	Nil	567	1739	44	1606	3160	251
700 to 800	Nil	179	1108	5	691	3000	289
Totals	31	11,020	5,387	468	6,349	7,656	728

From the above table and from Figures II and III it will be seen that 600° C. is a temperature below which the gases contain a preponderance of carbon dioxide, a moderate proportion of carbon monoxide, a relatively small amount of hydrogen and a fairly large percentage of unsaturated and paraffin hydrocarbons. This temperature, however, is one at which carbonization can be carried out on an industrial scale. Generally speaking, at temperatures of the order of 400°C., considerable practical difficulties arise which are not encountered at the higher temperature. It might thus be found economical not simply to dry such coals in the conventional way, but, in addition, to remove a large proportion of the oxygen at the expense of a certain proportion of the original available heat in order to produce a solid product in which the available heat is concentrated. Such a treatment appears to be the

FIGURE II

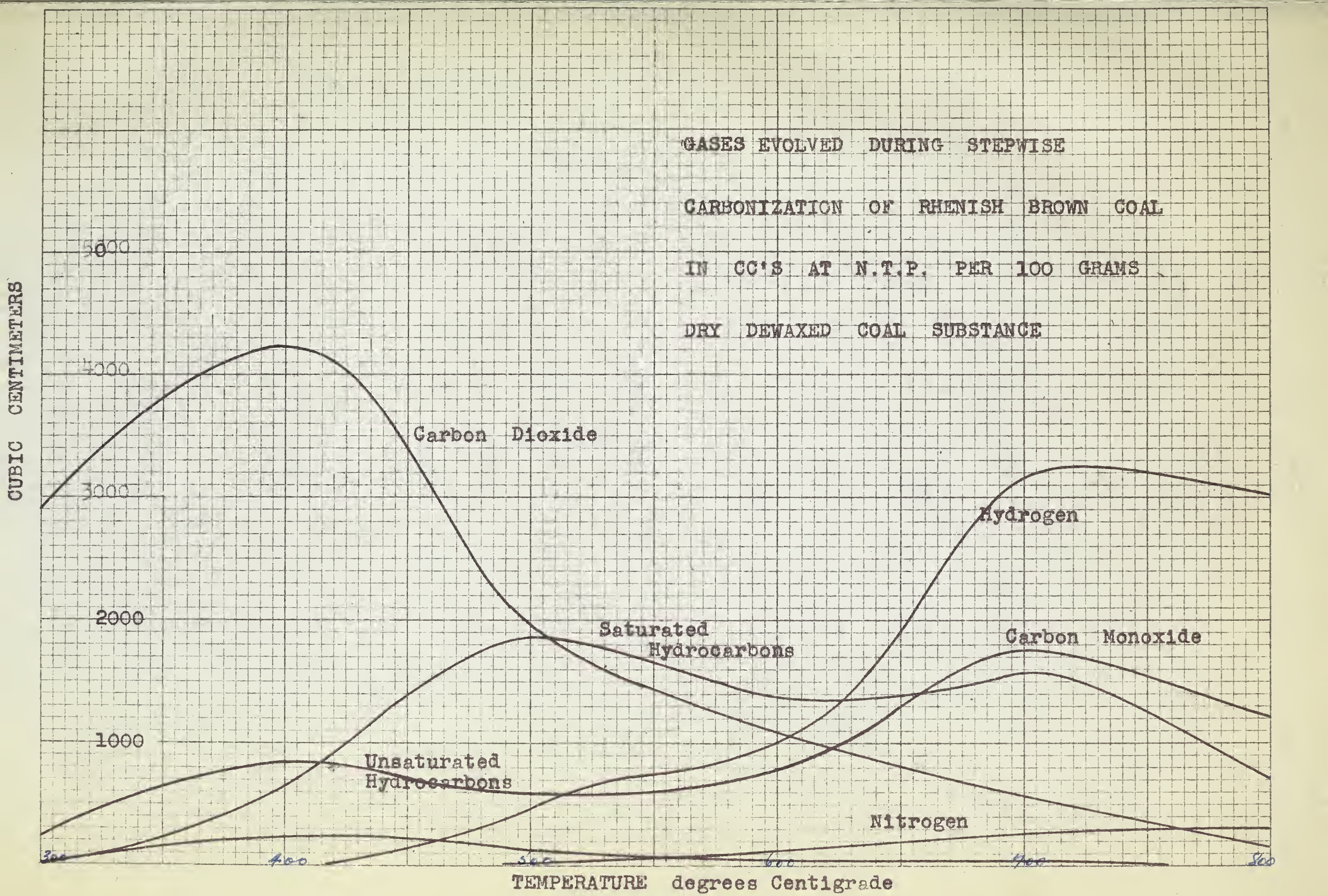
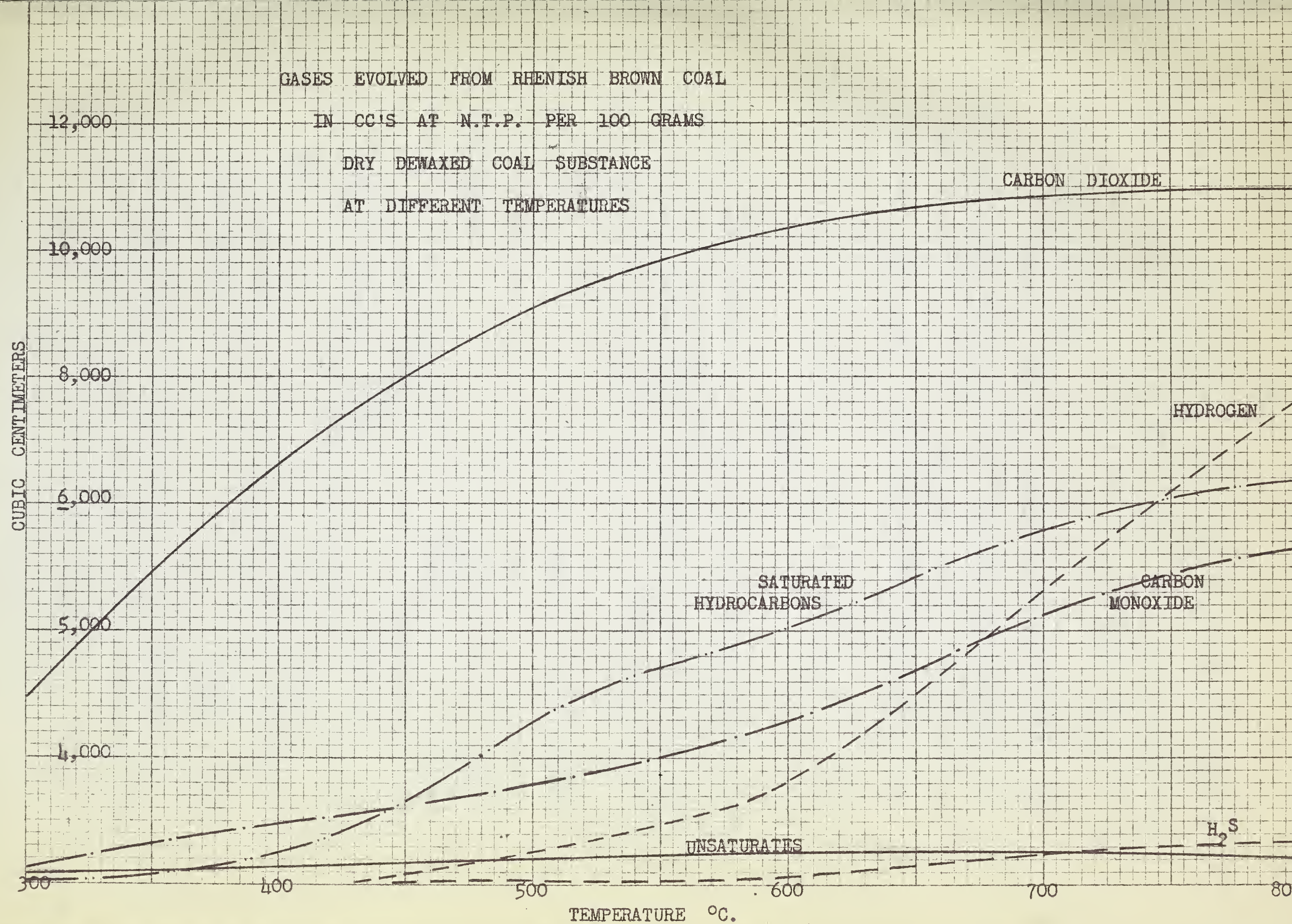

GASES EVOLVED DURING STEPWISE
CARBONIZATION OF RHENISH BROWN COAL
IN CC'S AT N.T.P. PER 100 GRAMS
DRY DEWAXED COAL SUBSTANCE
CUBIC CENTIMETERS
5000
4000
3000
2000
1000
Carbon Dioxide
Hydrogen
Saturated Hydrocarbons
Carbon Monoxide
Unsaturated Hydrocarbons
Nitrogen
300
400
500
600
700
800
TEMPERATURE degrees Centigrade

FIGURE III


GASES EVOLVED FROM RHENISH BROWN COAL
IN CC'S AT N.T.P. PER 100 GRAMS
DRY DEWAXED COAL SUBSTANCE
AT DIFFERENT TEMPERATURES
CUBIC CENTIMETERS
12,000
10,000
8,000
6,000
5,000
4,000
CARBON DIOXIDE
HYDROGEN
SATURATED HYDROCARBONS
CARBON MONOXIDE
H_2S
UNSATURATES
300
400
500
600
700
800
TEMPERATURE °C.

conception underlying the work of the Lignite Utilization Board of Canada in its attempt to design a low-temperature carbonization plant suitable for the treatment of Canadian subbituminous coals.

Comparable data are given by Stansfield (6) and his colleagues relative to the stepwise carbonization of a sample of Black Diamond coal, an Alberta type C subbituminous coal mined in the Clover Bar district of the Edmonton coal area.

Table X

Stepwise Carbonization of Black Diamond Subbituminous Coal

Proximate Composition	As Mined Basis Per cent.	Dry Basis Per cent.
Moisture	21.5	--
Ash	6.4	8.2
Volatile Matter	28.7	36.5
Fixed Carbon	43.4	55.3
	100.0	100.0
Calorific Value, B.t.u./lb.	9,040	11,510

Carbonized lignite at temp. of maximum calorific value	Per Cent.
Ash	11.6
Volatile Matter	7.9
Fixed Carbon	80.5
	100.0
Calorific Value, B.t.u. per lb.	13,450

Gain in Calorific value on Carbonization at specified temperatures. Dry Coal Basis	Per Cent.
350°C.	6.4
400	9.5
450	11.9
500	13.8
550	16.1
575	16.7
600	16.9
625	16.7
650	16.2
700	13.9
750	12.4
800	10.3

Maximum increase of calorific value	Per cent.
From coal as mined	48.8
From dry coal	16.9

Yield for maximum calorific value	Per cent.
From coal as mined	53
From dry coal	67

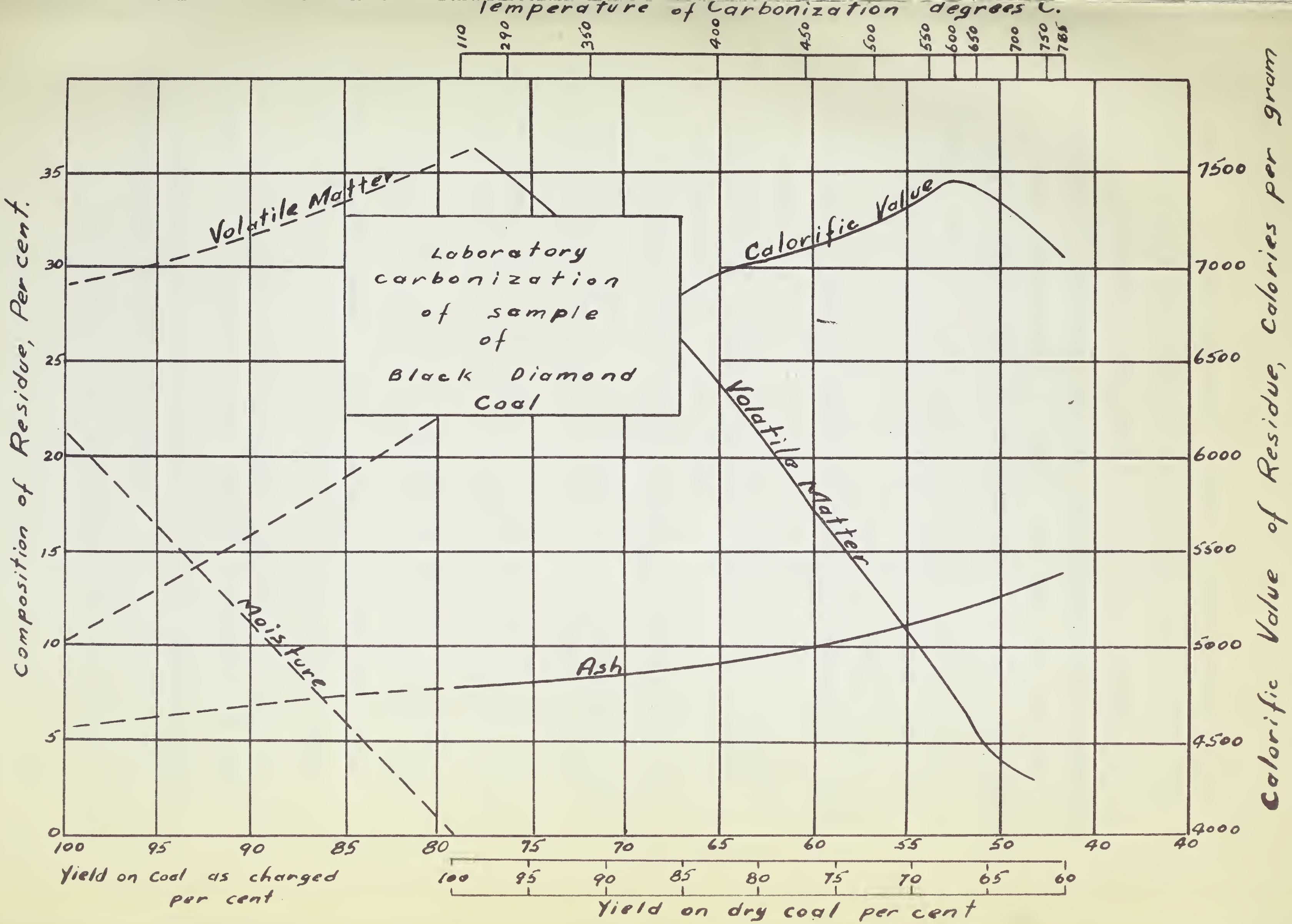
The above results are depicted graphically in Figure IV

Comparison of this Figure with Figure II shows that:

1. Up to a temperature of 110°C. the increase in the calorific value is the result essentially of the loss of water only.

2. Judging by Figure II, up to 300°C. the increase in calorific value apart from the further loss of water, is due principally to the large amount of oxides of carbon which are evolved at temperatures of the order of 400°C. It should be noted, however, that over this temperature range there is a considerable loss of heat due to the evolution of quantities of unsaturated hydrocarbons.

FIGURE IV


Temperature of Carbonization degrees C.
110
290
350
400
450
500
550
600
650
700
750
785
Laboratory carbonization of sample of Black Diamond Coal
Volatile Matter
Calorific Value
Volatile Matter
Moisture
Ash
Composition of Residue, Per cent.
35
30
25
20
15
10
5
0
Calorific Value of Residue, Calories per gram
7500
7000
6500
6000
5500
5000
4500
4000
100
95
90
85
80
75
70
65
60
55
50
40
40
Yield on Coal as charged per cent
100
95
90
85
80
75
70
65
60
Yield on dry coal per cent

3. Table X shows that 600°C. is an optimum carbonization temperature if a char of the maximum heating value is to be obtained. From Figure II it will be seen also that with immature coals of this nature, when a carbonization temperature of 600°C. has been attained, the bulk of the carbon dioxide has been evolved. At higher temperatures considerable amounts of carbon monoxide are evolved together with some quantities of paraffin hydrocarbons but the major loss above 600°C. appears to be due to a fairly copious evolution of hydrogen. This occurrence accounts for the calorific value of the char diminishing slightly only when carbonization temperatures of 600°C. are exceeded.

Whilst these results bring out clearly that the optimum temperature of carbonization for obtaining a char having a maximum calorific value is approximately 600°C., other important considerations arise, of course, if such a carbonization treatment of lignites or subbituminous coals is to be carried out on an industrial scale. It might, for example, be found more advantageous to increase the yield of the product at the expense of producing a char with a calorific value somewhat below the maximum value, if of course such was economically feasible. Moreover, the actual throughput of a plant, provided a reasonably satisfactory product is obtained is, of course, an over-riding consideration in plant operation.

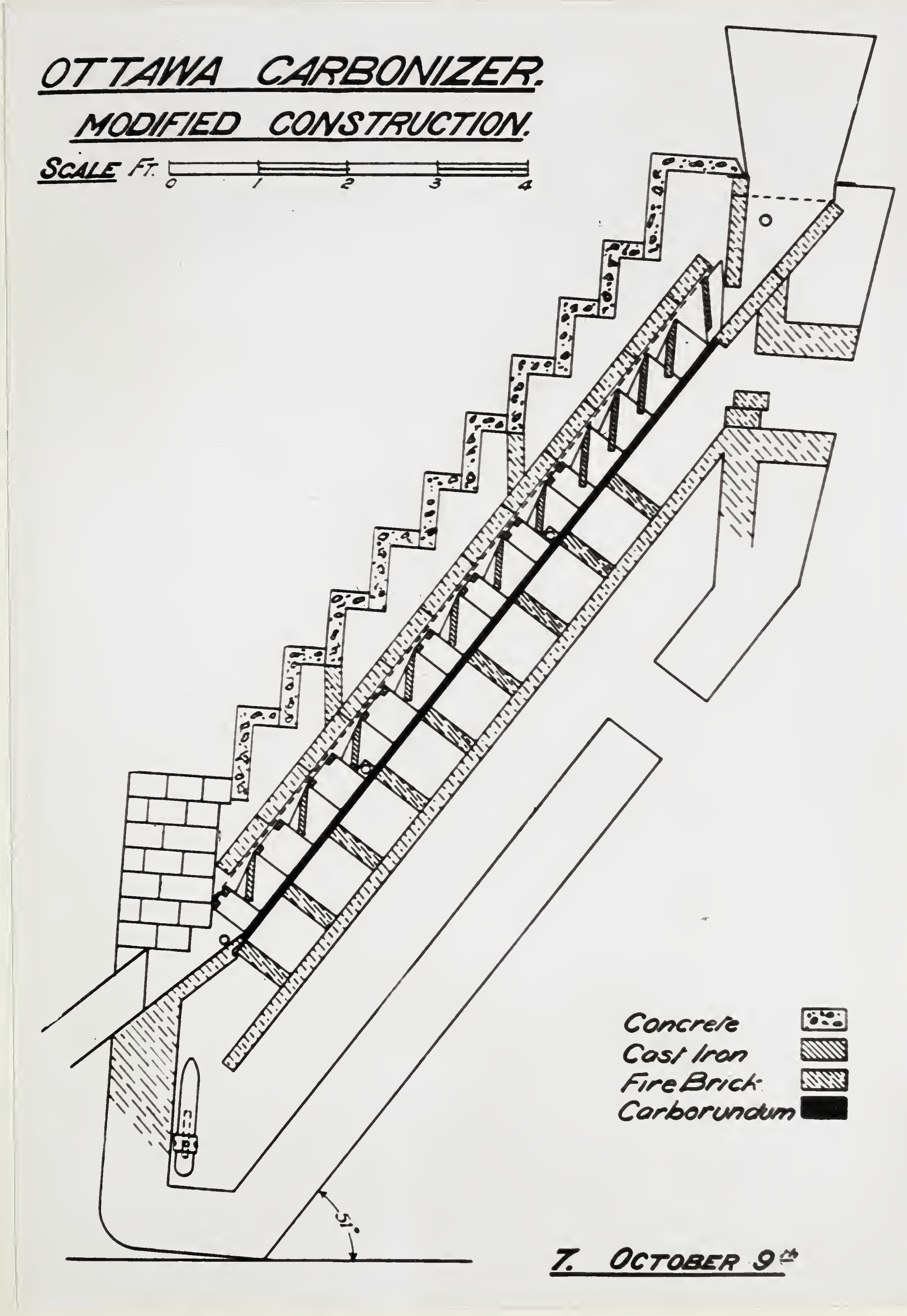
The carbonization of coking, as well as non-coking

coals, at temperatures of the order of 600°C. on a large scale has been attempted on numerous occasions but few of the plants which have been designed and operated have been found to work satisfactorily. Carbonization up to temperatures of about 600°C. is commonly spoken of as low-temperature carbonization, in contrast to high-temperature carbonization which refers to temperatures generally speaking above 1,000°C. In 1919, the Lignite Utilization Board (7), after surveying the plants then available for the low-temperature carbonization of materials such as lignites and subbituminous coals, arrived at the conclusion that no plant then existent was entirely suitable for the purpose.

Accordingly, after several tentative designs for a suitable retort had been considered by the Board, a design by Stansfield (7) was adopted and a small-scale experimental retort was erected in Ottawa and put into operation. The retort was designed to treat dried lignite and lignite containing a considerable proportion of slack could be treated satisfactorily. The design provided for the recovery of by-products, but owing to the retort not being air-tight, the gas had to be allowed to escape into the atmosphere and city gas was used to heat the retort. Later the design of this retort was modified, particularly with regard to the method of removing the gas and the tar vapours. Also the base of the retort was reconstructed, carborundum replacing the refactory tiles which had been employed earlier. The final design of the retort is shown in Figure V.

FIGURE V

Diagram of Stansfield Ottawa Carbonizer



OTTAWA CARBONIZER.
MODIFIED CONSTRUCTION.
SCALE FT. 0 1 2 3 4
Concrete
Cast Iron
Fire Brick
Carborundum
51°
7. OCTOBER 9th

As a result of tests carried out with this plant it was concluded that basically the plant was both workable and satisfactory. The partially-dried lignite could be carbonized to any desired extent. It will be noted that the steady flow of material through the retort was controlled simply by the speed of rotation of a discharge mechanism operating at the bottom of the retort, and that apparently no particular operational difficulties were met with in this respect. The chief trouble, however, appeared to be the maintenance of the retort in a gas-tight condition.

As a result of the experience gained with the small-scale experimental retort erected in Ottawa, a large-scale plant was in due course built at Bienfait in the Province of Saskatchewan. The carbonization unit consisted of six retorts arranged in three pairs, each retort being designed to have a production capacity of 16 tons of char per working day of 24 hours. Actually this production was never attained, the maximum being 8 tons daily. Two rotary driers were installed to dry the lignite before carbonization. Arrangements were made for the removal of the gas and the tar vapours from the retort for the recovery of by-products.

Typical figures for the proximate analyses of the lignite used and of the char produced from it are given in Table XI.

Table XI

	Proximate analysis of lignite as fed to retort, per cent.	Proximate analysis of char recovered, per cent.
Moisture	5.4	Nil
Volatile Matter	34.1	16.2
Ash	17.3	24.0
Fixed Carbon	43.2	59.8
	100.0	100.0

The yield of coke was 72.2 per cent. of the lignite as charged. The gas recovered amounted to 3940 cu. ft. per ton of lignite as charged or 2910 cu. ft. per ton of the raw lignite, which contained 30 per cent of moisture.

Considerable difficulties were encountered in the operation of this plant, some of the more notable being the following:

1. The baffles were inclined at 45° to the horizontal and this angle of inclination was found to be insufficient to permit the lignite to slide freely. The lignite used at Bienfait contained a considerably higher proportion of fine material than that used in the Ottawa experiments. The presence of this fine material markedly increased the angle of repose of the entire bulk of the lignite. Finely-divided material was retained on the base of the retort and this, presumably in a carbonized condition, substantially reduced the rate of heat transfer.

2. The clearance beneath the cast iron baffles, which regulated the thickness of the material undergoing treatment was too small, and the passage of the lignite between the baffles was stopped by large pieces of lignite and foreign material. It was not possible to clear the blockages by rodding from the top or the bottom of the retort. After a period of operation the cast-iron baffles became warped. Difficulties due to warping have been commonly met with in low temperature carbonization retorts constructed of metal which have been designed since the work of the Canadian Lignite Utilization Board ceased.
3. Carbonization conditions were not flexible. Satisfactory operation depended on close adjustments of the rates of feeding, discharge of material and on the maintenance of steady temperature and pressure conditions in the retort. If any of these varied slightly the entire operation of carbonization was affected adversely. No experimental details have been found in the literature descriptive of the operations of the plant which state specifically the effect on the operation of the retort of alterations in the rate of carbonization and the temperatures and pressures in the carbonization system.
4. The design of the plant was so intricate that skilled men were required for its operation, thus substantially adding to normal carbonization plant labor costs.
5. The original carbofrax (carborundum) floor tiles cracked badly and had to be replaced with fire-clay tiles of

greater thickness. This reduced the capacity of the plant even below that attained when the carbofrax tiles were used. The maximum capacity with the carbofrax construction was only 50 per cent of the estimated capacity and when fire-clay tiles were used the capacity diminished still further.

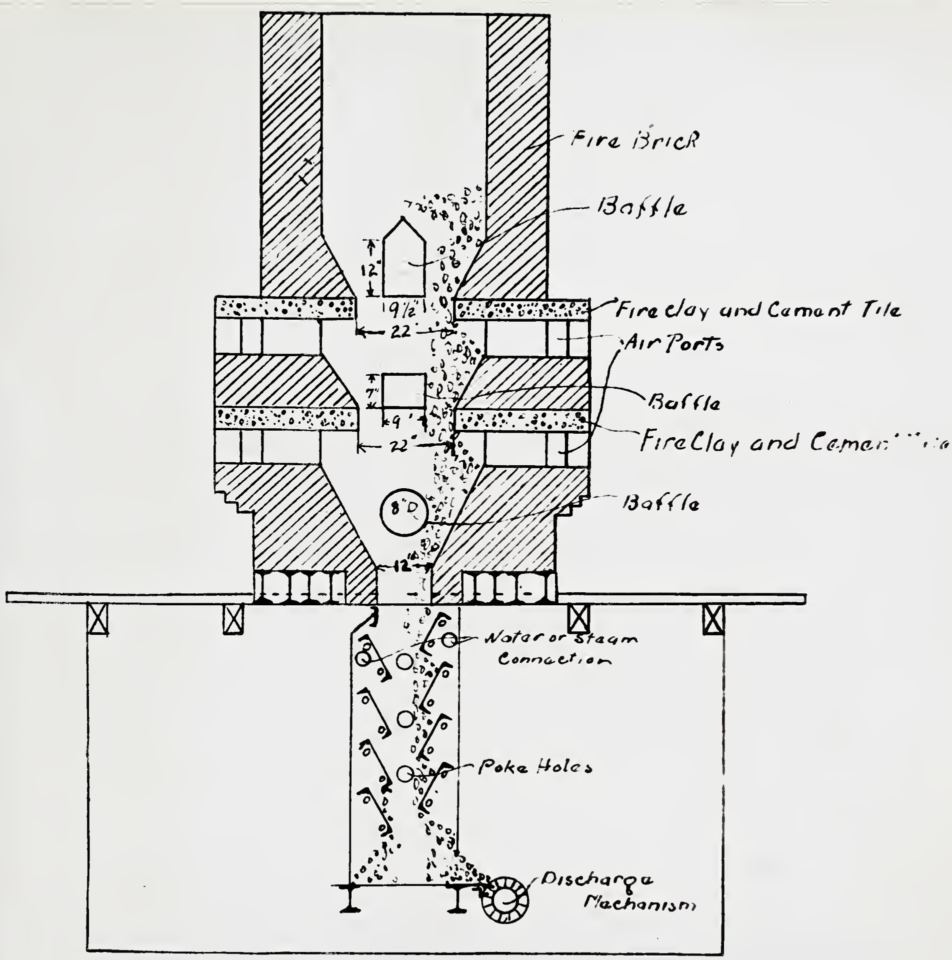
Ultimately these limitations and, in particular, the failure of the carbofrax construction led to the entire abandonment of this type of retort.

Meanwhile American investigators (8) had been carrying out experimental work of a similar type with a view to the exploitation of the lignite deposits of North Dakota. As a result of this experimental work, a plant known as the Hood-Odell had been constructed and had given more promising results than those obtained at Bienfait. Accordingly, the Canadian Lignite Utilization Board arranged for tests to be made on the Hood-Odell plant using lignite mined in the Bienfait area. Details of the design of the Hood-Odell plant are shown in Figure VI. The plant operated on an entirely different principle to that employed in the retorts designed and operated by the Canadian Lignite Utilization Board. In principle, the Hood-Odell plant was a shaft carbonizer working essentially on the principles of operation of a producer plant.

The upper portion of the carbonizer had a relatively large capacity and served essentially for the drying of the lignite before its passage through the carbonization and gasification zones. At two separate lower levels in the carbonizer, air was introduced through tuyeres passing through

FIGURE VI

Diagram of Hood-Odell Carbonizer


Fire Brick
Baffle
12"
19½"
22
Fire clay and Cement Tile
Air Ports
7"
9"
Baffle
22"
Baffle
8"D
12"
Water or Steam
Connection
Poke Holes
Discharge
Mechanism

the wall of the carbonizer. The lower section of the carbonizer was suitably tapered to provide for the decreased bulk of the lignite after passage through the drying and carbonization zones. The treated material passed from the lower section to a cooling chamber fitted with baffles and a mechanically-operated extractor to direct the flow of the material and to remove it from the carbonizer. In the early designs of this plant, it was found that the air flow tended to follow the sides of the carbonizer and accordingly, baffles were placed centrally to direct the flow of the material towards the centre of the carbonizer and to bring it into more intimate contact with the air. In later designs the top baffles were replaced with a slotted pipe through which gas and tar vapours could be withdrawn.

The plant was started up by igniting the lignite, introducing air through the tuyeres and then gradually building up the bed of fuel until the carbonizer was filled. Extraction was commenced and operations continued until steady conditions were obtained. Partial gasification of the lignite occurred, the heat from which served to carbonize the lignite above the gasification zone. This principle of operation is similar to that employed in the McLaurin plant (9) which was constructed along the lines of a blast furnace for the low-temperature carbonization of bituminous coal.

Results obtained on the Hood-Odell plant appeared to justify the erection of a similar plant at Bienfait. Typical figures for the proximate compositions of the lignite used and of the char obtained from it are given in Table XII.(7)

Table XII

Proximate Compositions of Lignite Used and of Char Obtained from the Hood-Odell Carbonizer

	Lignite as Charged, per cent.	Char Recovered, per cent.
Moisture	33.3	Nil
Volatile Matter	27.6	12.2
Ash	6.4	15.1
Fixed Carbon	32.7	72.7
	100.0	100.0
Calorific Value, gross B.t.u. per lb.	7,390	11,800

The char yield was 42.3 per cent. by weight of the lignite carbonized. 16,000 cu. ft. of gas with a gross heating value of 110 B.t.u. per cu. ft. were recovered per ton of lignite treated. The tar recovered amounted to 2.5 to 3.5 gallons per ton of lignite.

The results obtained with this plant were considered encouraging, but unfortunately by this time, December 31, 1923, the Canadian Lignite Utilization Board had to cease operations owing to lack of financial resources. After a period of about 5 years, the plant was disposed of to a private company for the nominal sum of one dollar.

Whilst these developments were proceeding on the North American Continent a considerable amount of experimental work in the low-temperature carbonization of lignite had been taking place in Germany. It is not necessary to attempt even a general account of these developments but only to make mention of two retort systems which have a direct bearing on

the design and operation of the retort developed by the Research Council of Alberta and described in detail later.

The Limberg retort was developed in Germany after the First Great War. Figure VII (10) shows the construction of this retort. The drying and carbonizing is carried out by means of clean hot gases circulated through the charge.

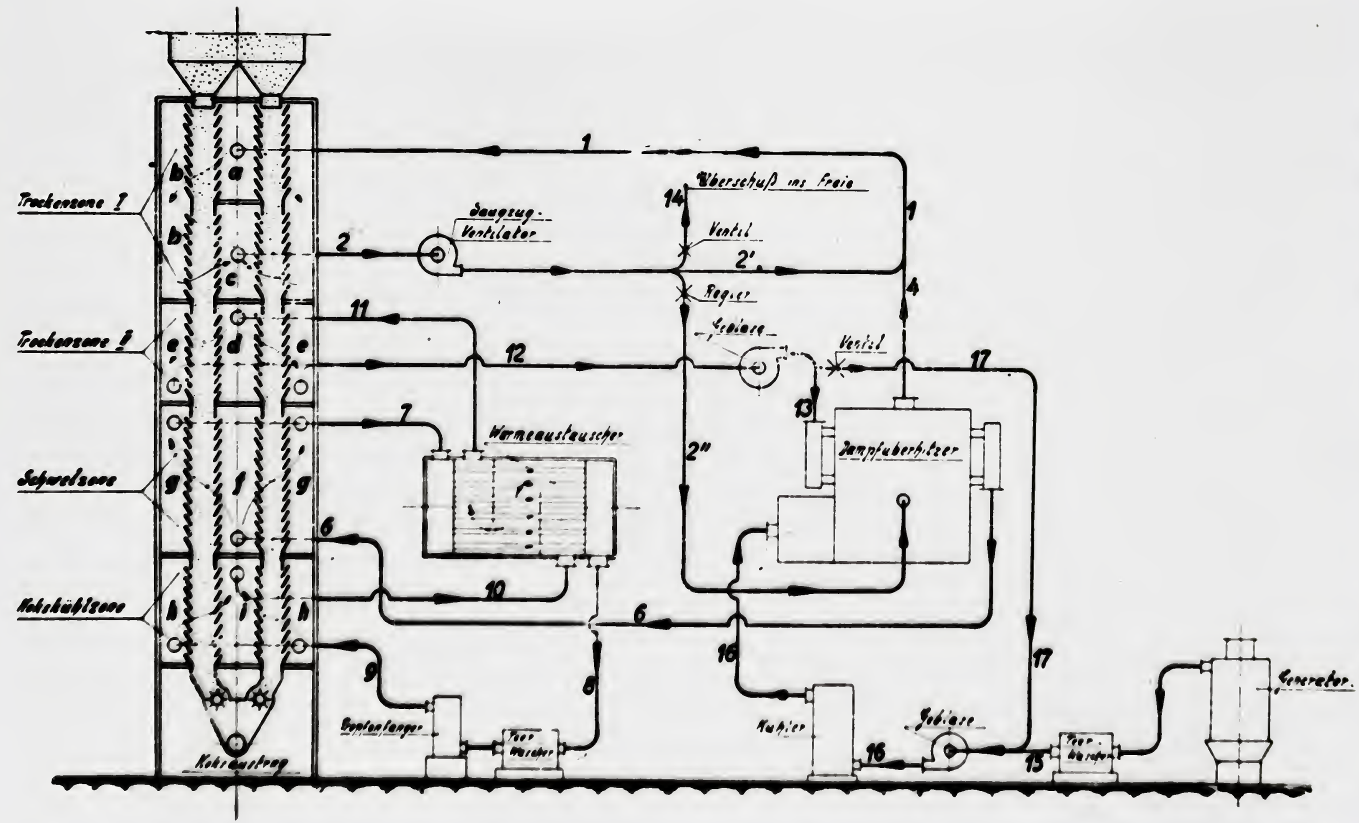
Gas from the carbonizing zone is cooled in a heat exchanger, cleaned, and then used for cooling the coke. It later passes in counterflow through the same exchanger, and is then heated and passed to the second drier. From the drier it divides into two streams, one flowing to a gas heater where the gas is burned and the second to the same heater where this portion of the gas is pre-heated and returns to the retort for carbonization of the coal. A small producer is maintained to supply auxiliary gas for starting up the process.

A second cycle occurs in the first drier. The saturated gas leaves the drier and is divided into three streams. Part of the gas is circulated back to the drier, a second portion is sent to the gas heater, and after being heated joins the first stream and thence to the drier, and the third stream is bled to the atmosphere.

The second retort of which mention must be made was also designed in Germany at a later date by Lurgi.(11). The Lurgi retort has within recent years been considerably modified and brought to the stage of successful operation on an industrial scale. A diagram of the Lurgi plant is shown in Figure VIII. (12)

FIGURE VII

Diagram of Limberg Carbonizer

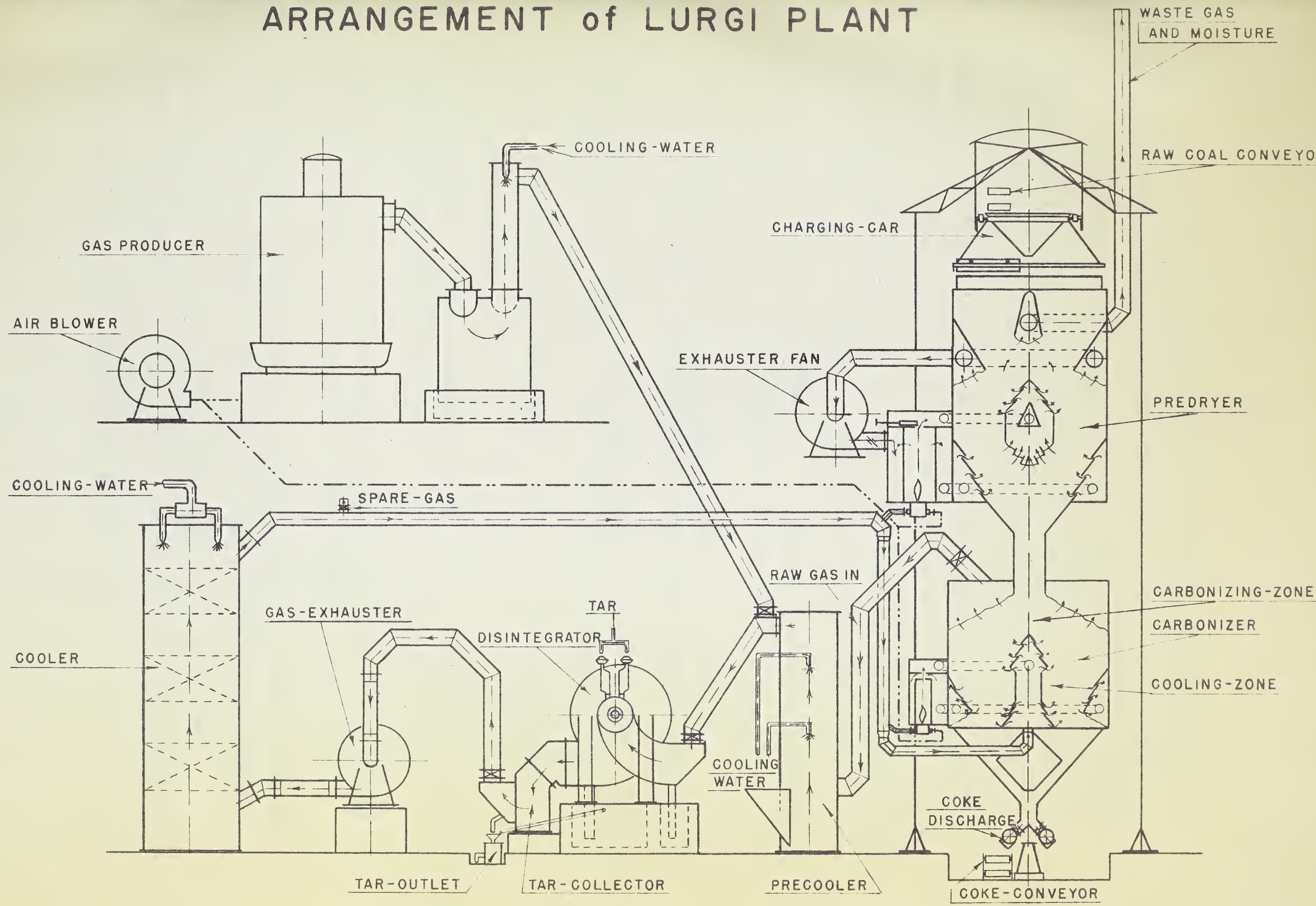


Trockenzone I
Trockenzone II
Schwelzone
Kokskühlzone
Koksaustrag
Saugzug-Ventilator
Überschuß ins Freie
Ventil
Regler
Gebläse
Ventil
Wärmeaustauscher
Dampfüberhitzer
Kühler
Gebläse
Generator

FIGURE VIII

Diagram of Lurgi Carbonizer

ARRANGEMENT of LURGI PLANT



It will be seen that in the Lurgi plant while the general principle of the shaft carbonizer has been retained, very considerable modifications have been introduced. Essentially the plant is divided into two portions, the upper a drying portion and lower a carbonizing portion. The dry material is carbonized by means of the sensible heat of hot combustion gases derived from the burning of a portion of the gas recovered during the process of carbonization and gasification. The gas is withdrawn from the carbonization zone by means of an exhauster, cleaned by passage through scrubbers and a part of it is then burned in a combustion chamber built alongside the carbonizing section of the plant.

The heat requirements of the whole process are said to be such that there is an appreciable surplus of gas. Gas introduced at the base of the carbonizing portion of the retort serves to cool the coke. This gas along with gas from carbonization of the lignite passes to the scrubbers for cleaning. Thus in this portion of the plant there is a continual circulation of gas of which a relatively small quantity is burned to provide the heat for the carbonization of the lignite. It should be noticed that, besides the sensible heat derived from the combustion of a small portion of the gas produced, some heat is also generated by partial gasification of the material which takes place in the carbonizing section of the plant, owing to the oxygen necessarily present in the combustion gases.

A second small part of the gas is burned in a small combustion chamber built along the carbonizer at the level of the bottom of the drying section. The combustion gases are caused to pass through the drier by means of an exhaust fan which delivers these gases and water vapor from the drier to a stack and so to the atmosphere.

For the purpose of starting the plant, a separate gas producer is provided and producer gas is burned in the two chambers already mentioned.

It is stated that: (12)

1. The temperature of the exhaust gas in the dryer is such that the sensible heat of the gas is fully utilized.
2. The temperature of the carbonizing zone is approximately 640°C.
3. The cooling of the coke is efficient since its temperature, on leaving the extractor, is only slightly in excess of 100°C.
4. The principle heat losses of the plant are due to the cooling of the gas during its cleaning.

Two such Lurgi retorts were installed at Bienfait following cessation of operations by the Canadian Lignite Utilization Board and are still in operation.

Development of the Lurgi system of low-temperature carbonization has continued in Germany. Reports obtained by investigating teams after hostilities ceased show that development has been in two directions.

In one instance the retort has been modified to carbonize briquettes. Brown coal is first dried and then briquetted without the addition of any binder. The briquettes are then carbonized in a retort of the Lurgi type now known as the Lurgi-Spülgas retort. (13) A diagram of this retort is shown in Figure IX.

Each Lurgi-Spülgas unit of two separate vertical shafts is placed one on each side of central combustion chambers supplying the heating gases. The capacity of a plant comprising ten such units is stated to have been 3000 metric tons per working day. As in the case of the Bienfait plant the heating of the charge in both the drying and carbonizing sections is effected by means of the products of combustion of a portion of the gas produced in the retorts after the by-products have been recovered.

The second type of the Lurgi retort, developed in Germany during the last war is known as the Krupp-Lurgi. (14) This retort is externally heated and operates on the batch system. A diagram of the Krupp-Lurgi retort is shown in Figure X. Each retort has seven hollow heating chambers through which heating gases are circulated to effect carbonization. The heat for the retorts is obtained by burning the gas from carbonization after it has been cleaned. The combustion gases enter the heating chambers at a temperature of 620°C. The time of carbonizing of one charge of lignite or coal is stated to be 5.34 hours. A plant of this type situated near Velsen, in the Saar, consisted of 16 retorts and had a total capacity of 180 tons of coal per day.

FIGURE IX

Diagram of Lurgi-Spülgas Retort

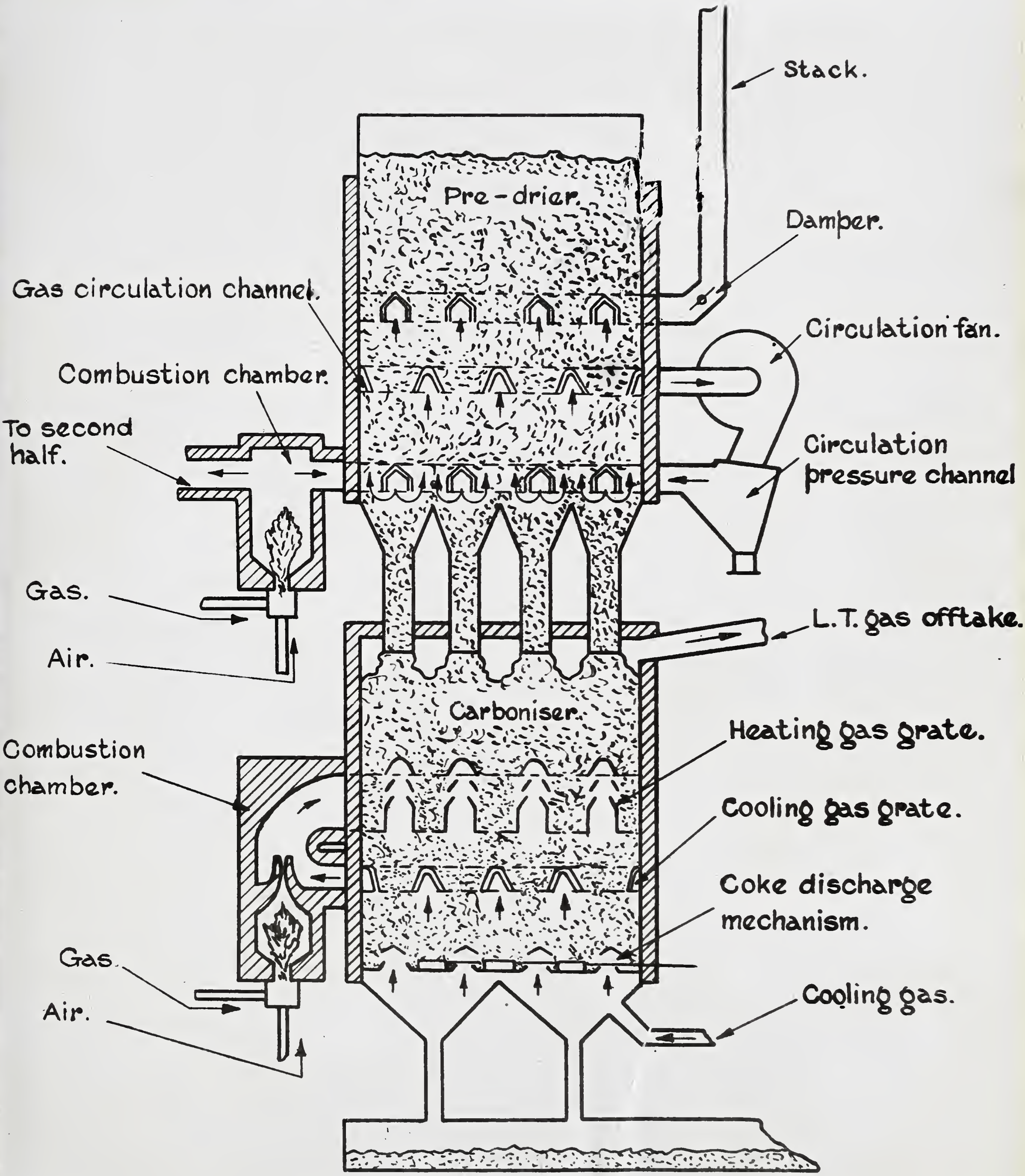

Stack.
Pre-drier.
Damper.
Gas circulation channel.
Circulation fan.
Combustion chamber.
To second half.
Circulation pressure channel
Gas.
L.T. gas offtake.
Air.
Carboniser.
Heating gas grate.
Combustion chamber.
Cooling gas grate.
Coke discharge mechanism.
Gas.
Cooling gas.
Air.

FIGURE X

Diagram of Krupp-Lurgi Retort

DIAGRAM OF KRUPP - LURGI LOW TEMPERATURE CARBONISING PLANT

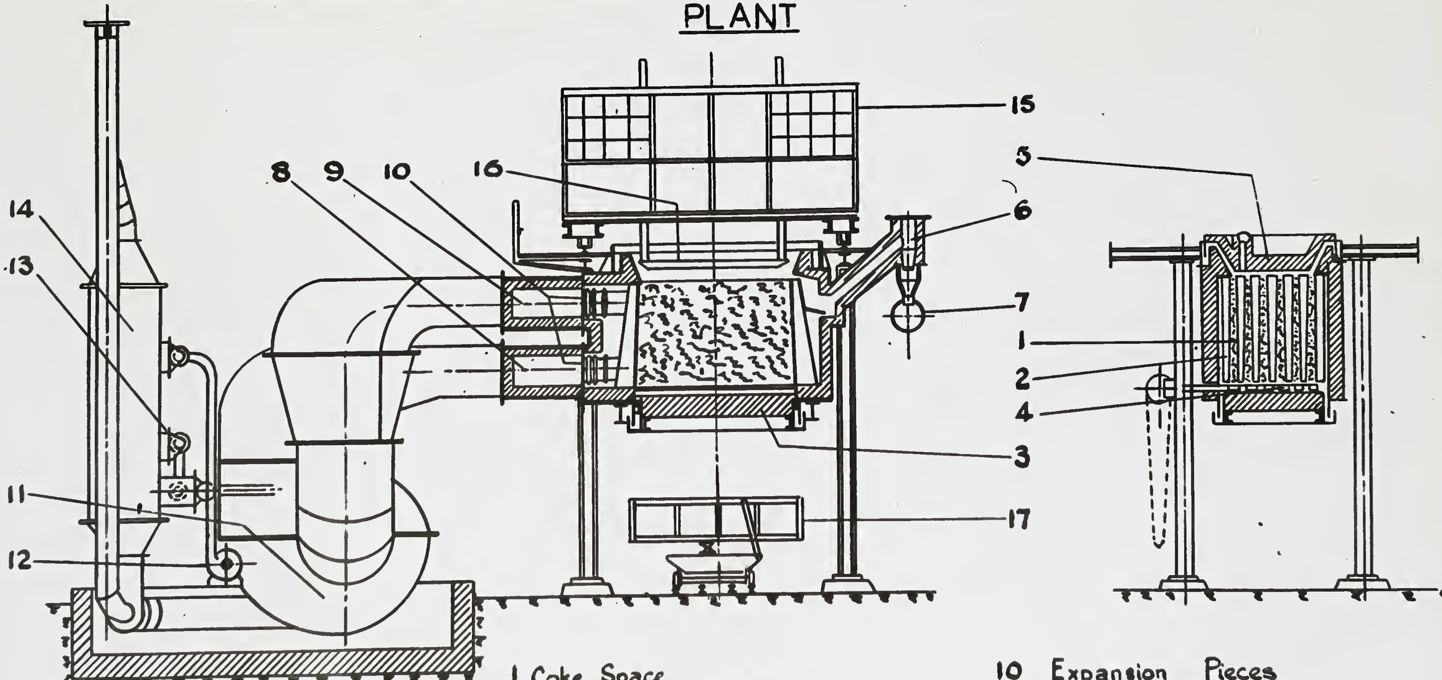


Fig. 1

1 Coke Space
2 Heating Elements
3 Water Sealed Bottom Door
4 Movable Grid
5 Water Sealed Top Cover
6 Gas Offtake
7 Collecting Main
8 Heating Gas Inlet
9 Heating Gas Outlet
10 Expansion Pieces
11 Main Circulating Fan
12 'Air to Burner' Fan
13 Gas Burner
14 Heat Exchanger
15 Coal Charging Machine
16 Stamp Bars
17 Coke Car

III. Design and Construction of the Research Council of Alberta Retort.

My research commenced in March 1946 under the direction of Mr. Edgar Stansfield, Chief Research Engineer of the Research Council of Alberta. From a survey of relevant literature and from past experience it had been concluded that a satisfactory retort could be constructed which would carbonize slack coal. The features considered necessary in the design were:

1. Continuous operation by internal heating in a retort of vertical design to allow of gravity flow.
2. The retort need be designed to carbonize non-coking coals only.
3. No attempt should be made to recover by-products.
4. The period of carbonization should be as short as possible.
5. To provide for maximum heat transfer, the volatile products should be burned in the closest proximity to the coal, this to be accomplished by the controlled introduction of air into the retort.
6. In order to minimize the extent of combustion or gasification of the char, contact with air or combustion gases should be minimized. The heat required for carbonization and derived from combustion of the volatile products, should be transferred to the coal without having to pass through a furnace wall.
7. The least possible breakage of coal or char should occur during carbonization.

A retort thought to embody all these features had already been designed and built on a small scale and had been operated for a short period. It was at this stage that I was called on to assist in the design, construction, operation and testing of a plant of a similar design but with an estimated throughput of approximately 200 lbs. of coal per hour. The essential features of the retort had already been established, but the construction of the larger retort necessitated recalculations particularly of the size of the flues which would be required for the larger quantities of volatile matter.

Figure XI shows a cross section of the retort with constructional details. This design of retort seems to have been developed from the various designs used by the Canadian Lignite Utilization Board, where a system of baffles was repeatedly employed. In addition, the retort embodies the principle of the Hood-Odell and the Lurgi plants in which the air or flue gases used in the carbonization process are brought in direct contact with the lignite undergoing carbonization. The novelty of the design lies in that whilst combustion gases are brought into contact with the material, the contact is not as intimate as in the Lurgi process and thus partial gasification of the material is minimized. The use of baffles overcomes the difficulty of obtaining an even flow of gas through a solid fuel bed, a matter which is especially important when the coal undergoing treatment contains a considerable portion

FIGURE XI

Cross Section of Reaearch Council Of Alberta Carbonizer

Insert

Foldout

Here

of fine material. In brief, the retort represents an attempt to utilize the valuable features of retorts designed by the Canadian Lignite Utilization Board and of the Hood-Odell and the Lurgi systems. Its construction shows a fairly close similarity to the Limberg retort but the principle of operation is essentially different.

In the description of the retort in the succeeding pages, the various parts are designated by letters corresponding to those used in Figure XI.

1. <u>Divisions of Retort</u>

The retort could be divided along its length into three zones. In the top zone of the retort, the coal would be dried and preheated, in the middle zone carbonization would take place and in the bottom zone time would allow of completion of the carbonization. No air was supplied to the lowest section of the retort.

At the time the plant was designed it was not possible to say what would be the lengths of the drying, carbonizing and equalizing zones. The length of these zones had to be assumed in the light of experience and on the assumption that drying, preheating and carbonization would take place substantially in the zones already enumerated.

2. <u>Baffles</u>

The baffles (T) were made of carborundum and were supported by slotted carborundum end plates (U). The baffles were 9 in. x 6 in. x 3/4 in.; the end plates were 6 in. x 3 3/4 in. x 1 in. with slots 25/32 in. wide and 3/8 in. deep

set at an angle of 60° with the horizontal. The baffles were staggered to prevent bridging. One end plate was cut in half to provide a support 3 in. high for the first baffle. This first baffle consisted of a "plicast" block cast between the two small end plates. Carborundum was chosen as the building material because of its strength, non-reactivity with hot char, high conductivity and its ability to withstand abrasion. The plates and baffles were purchased ready made from the Canadian Carborundum Co., Niagara Falls, Ontario.

3. Calculation of Flue Spaces

In order to calculate the size of the flues which would be required, it was necessary to know the quantity and quality of the volatile matter produced by carbonization of the coal at a temperature of approximately 600°C. From previous experimental work, it was assumed that the carbonization of 100 lbs. of a C type subbituminous coal having a calorific value of 8,500 B.t.u. per lb., would produce approximately 50 lb. of char with a calorific value of 13,000 B.t.u. per lb., that is to say the carbonization of 100 lb. of coal would make available 200,000 B.t.u. on complete combustion of the volatile matter.

It was further assumed that, under normal conditions of working, complete combustion would not be obtained and that only 75 per cent. of the total heat available would be developed in the flues. This would be equivalent to 150,000 B.t.u. for every 100 lb. of coal treated. The composition of the volatile matter was not known precisely,

and no exact allowance could be made for heat available in the tar vapours. The broad assumption was, therefore, made that the gas would be similar to a low-temperature gas from this type of coal, but its available heat would be somewhat increased because of the tar vapours.

One volume of a typical low-temperature carbonization gas has a theoretical air requirement of approximately 8 1/4 volumes of air. (15) The gas has a gross calorific value of about 900 B.t.u. per cu. ft., measured under standard conditions which, distributed in the theoretical combustion products represents approximately 100 B.t.u. per cu. ft. of combustion gas. In other words, by the addition of 8 1/4 volumes of air, 9 1/4 volumes of flue gas would be produced under theoretical conditions of combustion equivalent to the development of approximately 100 B.t.u. per cu. ft. of air. This makes no allowance for excess air but in view of the lack of precise data, it was considered that a round figure of 100 B.t.u. per cu. ft. would be satisfactory for the calculation of the size of the flues.

Accordingly, for the combustion of the volatile matter per 100 lb. of coal, that is, for the development of 150,000 B.t.u. 1500 cu. ft. of air at N.T.P. would have to be supplied. Correcting this volume to a basis of measurement at 20°C. and 700 mm. mercury pressure, the amount of air required per 100 lb. of coal $= 1500 \times \frac{293}{273} \times \frac{760}{700} = 1750$ cu.ft.

If the maximum capacity of the retort is assumed to be 200 lb. of coal per hour, the total air required is

thus 3500 cu. ft. per hour or 58 cu. ft. per min.

The total volume of the flue gas is thus approximately 9/8 x 1750 = 1970 cu. ft. per 100 lb. coal carbonized. A round figure of 2000 cu. ft. was taken as the volume of flue gas which would have to be handled. The exit temperature of the flue gas was, of course, unknown but it was assumed that it would be approximately 150°C. It was also assumed that the retort would operate with the pressure at the top of the retort approximately atmospheric. The flue gas volume under these conditions would be:

$2000 \times \frac{423}{293}$ or approximately 3200 cu. ft. per 100 lb.

coal or 6400 cu. ft. per hour for a maximum coal rate of 200 lb. per hour. This is equivalent to 1.78 cu. ft. per second. It was considered desirable to maintain a reasonably slow upward velocity of gas in the flues in order to give the maximum time for combustion to take place and to allow of the drying of the coal. In determining the diameter of a chimney, the velocity of the chimney gas generally employed is of the order of 15 or 16 feet per second, rising in exceptional cases to 20 feet per second. Since it was desired to maintain the hot gases in contact with the coal for the longest possible period of time, it was decided to work on the basis of a velocity of about 5 feet per second.

With the length of the flues determined by the length of the carborundum baffles, the width of the flues to give the desired gas velocity of about 5 feet per second was found to be 3 inches.

4. Dimensions of Retort

The height of the carbonizer, as determined by the available space in the laboratory, was 224 inches. In order to obtain the maximum space for cooling the char, the longest traverse of the coal through the drying and carbonizing zones, and in order to leave sufficient space for a hopper containing at least 30 minutes supply of coal with probable rates of discharge, the dimensioning of the plant was as follows:

(a) Stand supporting retort and containing the cooler - 36 inches in height.

(b) Overall height of retort from top of stand to exit of hopper - 174 inches.

(c) Height of hopper - 14 inches.

It was considered that the three zones in the retort would be represented by:

(a) 34 inches from the outlet of the hopper for the drying and preheating zone. To permit greater contact between the coal and the baffles in this zone, the number of baffles here was increased, this being made possible by bringing them closer together vertically. End plates 4 1/2 ins. high, instead of 6 ins. as in the carbonization zone, were, therefore, used. These end plates were cast in the laboratory from Plicast cement. To allow the coal to remain in the drying and preheating section for a longer period of time, the coal passage in this zone was made 2 1/2 inches wide

compared with 1 1/2 in. in the carbonization zone.

(b) The carbonization zone was 140 inches long. Exactly where the demarcation line between the drying and preheating zone and the carbonization zone would occur in operation was, of course, unknown.

(c) The equalizer zone consisted of the remaining 36 inches of the retort. Here too, the width of the coal passage was increased by one inch in order to allow a greater length of time for the larger pieces to lose their volatile matter. The end plates used in the equalizing zone were of the standard carborundum type and were cemented in place with Plicast cement.

5. <u>Construction</u>

The retort was insulated by means of G - 26 porous fire brick. As viewed in Figure XI, in the front and back of the coal passage the insulation consisted of one and one half bricks on end - a total thickness of 3 3/4 inches. The whole bricks were grooved to hold the end plates; the half bricks were set behind the whole bricks in a staggered manner to produce a more gas-tight setting. The sides of the retort were insulated by means of fire bricks laid flat as shown at (G) for a distance of 36 inches to 82 inches as measured from the base of the retort. In the next 54 inches the bricks were set on end as shown at (F) and in the top 38 inches half bricks were used as at (D). The thickness of the insulation was reduced as these separate steps were made in order to provide larger flue spaces towards the top

of the retort and to make provision for water vapour evolved in the drying zone.

The whole of the retort was enclosed in a 24 1/4 ins. x 16 3/4 ins. galvanized 22 gauge sheet iron casing (C). This casing was made in two 87 inch sections set one above the other. Each section was made up of a three-sided enclosure and a front plate. All metal sections had one inch flanges, so that the two sections could be bolted to one another and the front plate could be bolted to the three-sided enclosure. The sections were fastened together with 1/4 inch stove bolts spaced two inches apart. One-half inch, iron straps were used on both sides of the flanges for increased strength.

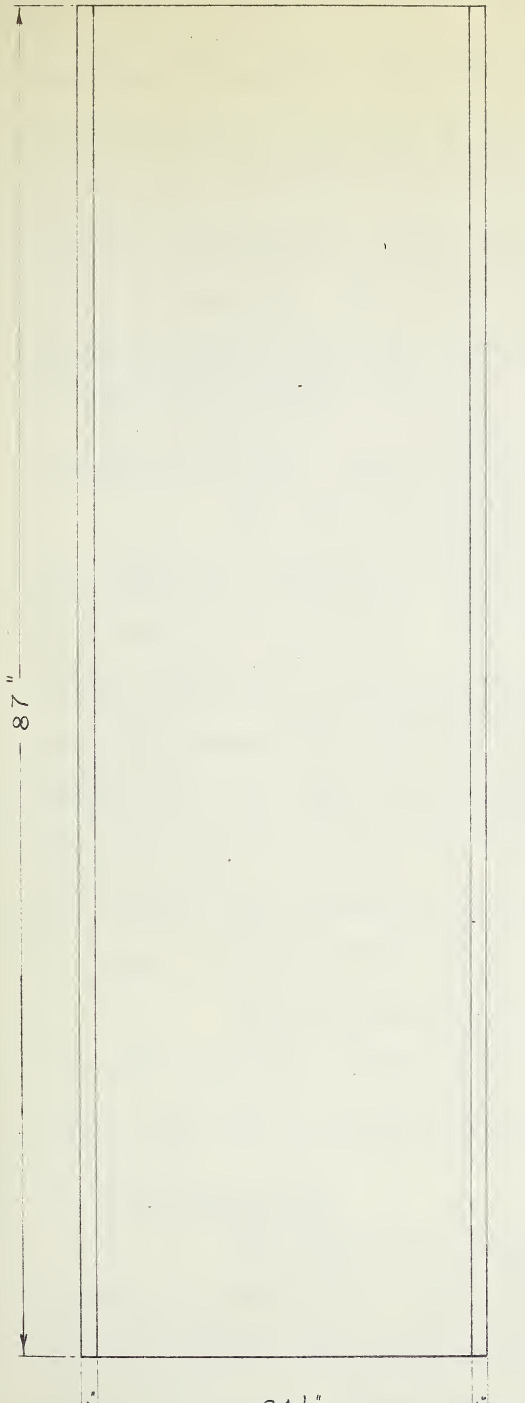
The metal enclosure was lined with asbestos paper, this paper being carried out to the ends of the flanges. The ends of the asbestos paper were smeared with furnace cement to provide an air-tight seal. A drawing of the casing and flanges is shown in Figure XII.

The hopper (A) was 20 inches square and 8 inches high, sloping to an 8 in. by 8 in. neck into the retort. The top of the neck was welded to a plate (B) which was bolted to the top of the metal casing. The neck protruded three inches into the retort to prevent any coal falling past the baffles.

The bottom of the casing was bolted to a 1/4 inch steel plate (O) shown in Figure XII. In this plate an 8 in. x 6 1/4 in. opening was cut out to allow for the

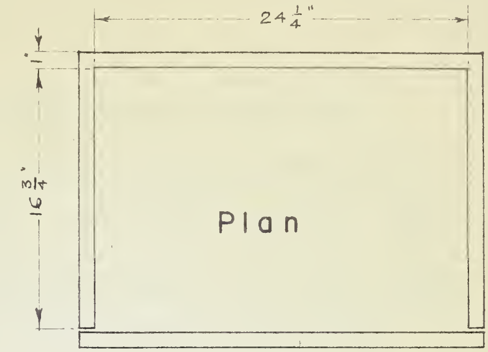
FIGURE XII

Diagram of Casing, Base Plate and Rake

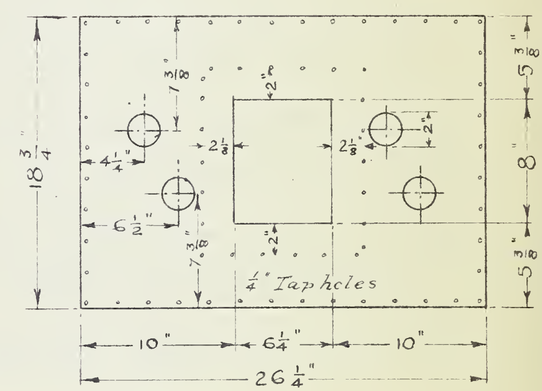


Elevation

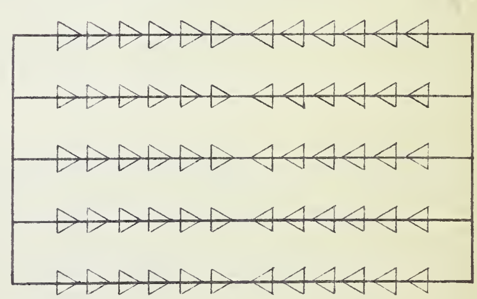
CASING.



Cover



Base Plate



Discharge Rake

discharge of coal; two inch diameter holes (V) and (P) were drilled as air inlets and the holes (Z,Z) as observation ports into the combustion chambers. Two inch lock nuts were welded to the plate around the holes to enable two inch pipes to be screwed in. The plate was covered with 1 1/4 inch thick firebrick (N) with openings cut to correspond with those in the steel plate. A sheet of asbestos paper was placed between the steel plate and the firebrick.

In order to preheat the combustion air, the air was admitted through the two 2 inch inlets (V) and (P) into preheater sections (M). The preheating passages were 1 1/2 inches wide and 36 inches high and were made by partitioning the flue space with baffles (L). The preheated air was introduced into the combustion chambers through the three passages (H) on each flue side, and then through the small openings (I), which were spaced a brick distance apart over a vertical distance of nearly four feet.

Into the observation holes (Z,Z) were screwed two inch nipples. These were covered with glass windows which were kept in place with metal rings retained by springs.

6. Cooling System

The char was cooled by passing through a water-jacketed cooler (W). Two 3 inch passages provided a superficial cooling area of 1770 square inches and a volume of 2380 cu. inches. Cold water was introduced through a half inch pipe (X) at the bottom of the cooler and withdrawn through two half inch pipes at the top. To the bottom of the cooler was welded a pan (Y) to house the discharge rakes.

The cooler was bolted to the bottom of the carbonizer base plate. Figure XIII shows the construction of the cooler.

7. Stand

The retort rested on a two inch angle iron stand, 36 inches high.

8. Method of Discharge

The char was removed by the reciprocating motion of a rake shown in Figure XII. This rake consisted of 5 one half inch metal strips spaced 4 inches apart and held at the ends by similar strips at right angles. To the metal strips were bolted other thin strips of metal in such a manner as to give a toothed effect. The spaces were filled with furnace cement to provide extra strength. This rake was suspended from the top of the stand by four metal strips and could swing freely.

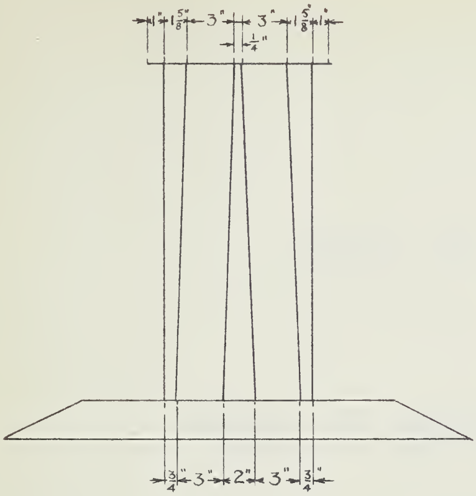
The rake was driven by an eccentric which was directly connected to a Graham variable reducer, which in turn was directly connected to a 1/4 H.P. motor. The stroke of the rake was four inches. The Graham variable drive could be controlled to give any desired rate of throughput,

9. Flue Gas Removal

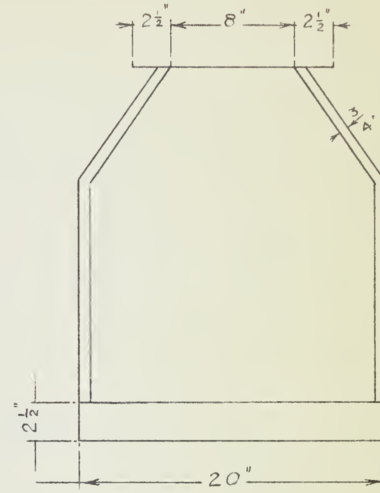
The combustion gases entering the flues were removed by two 5 inch pipes (S) each ten inches long, leading to a common main. The top of the main led to the stack by means of a six inch pipe and the bottom to an overflow container to catch any condensed moisture. A side arm from this lower pipe led to an exhauster and thence by a four inch

FIGURE XIII

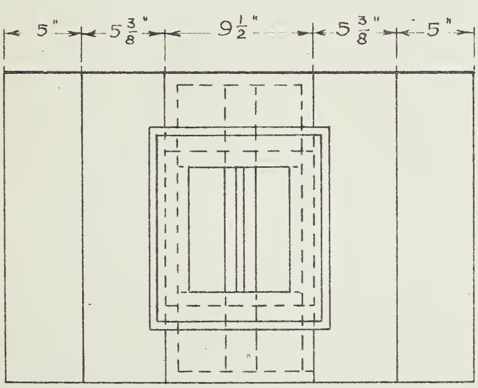
Diagram of Cooler



Elevation.



Side View



Plan

COOLER

FIGURE XIV

Diagram of Exhaust System

pipe to a second chimney. A diagram of the exhaust system is shown in Figure XIV.

10. Air Supply

The air was supplied by a DFC air blower driven by a 1/2 H.P. motor rated to supply 140 c.f.m. at a pressure of 10 inches water gauge. The flow was measured by a 2 inch Fischer and Porter rotameter. From the rotameter the air flow is divided into two 2 inch lines leading to the retort. Three valves were set in the lines, one just above the rotameter and one on each of the two individual streams.

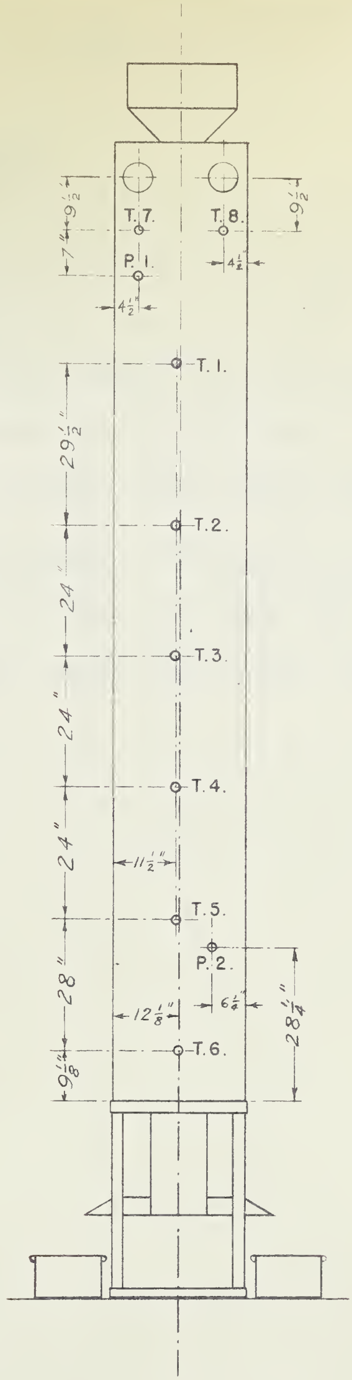
11. Temperature Control

Temperatures were measured at six points down the coal stream by means of chromel-alumel thermocouples. The thermocouples were encased in closed silica tubes, inserted through holes in the metal casing, insulation bricks and carborundum plates and protruded 3 inches into the coal stream. The thermocouples were connected by means of compensating leads to a central switch and then to a manually-operated potentiometer. The positions of the thermocouples are shown in Figure XV and are referred to in this thesis as T.C. 1, 2, 3, etc.

The flue temperatures were taken by means of 2 iron-constantan thermocouples placed centrally in the flue gas streams, 9 1/2 inches below the centre of the exhaust outlets (S). These were connected to a Leeds-Northrup automatic recorder which gave continuous readings in degrees Fahrenheit. The readings are referred to later as 7 and 8, respectively.

FIGURE XV

Arrangement of Thermocouples and Pressure Outlets



POSITIONS OF THERMOCOUPLES
AND PRESSURE OUTLETS.

12. Pressure Control

Pressures were measured at two points in the combustion chambers of the retort by means of inclined manometers calibrated in inches of water. One point was 16 1/2 inches below the centre of the west flue outlet and the other 28 1/4 inches above the base of the east flue. The pressures are designated P_1 and P_2 respectively.

13. Other equipment included a 240 lb. weighing scale calibrated to 1/4 lb., loading buckets, pulley and rope for filling the hopper with coal, char pans and so forth.

IV. PRELIMINARY TESTS

The retort was erected originally in a position where space was very confined and where the fire hazard was such as to make it undesirable to leave the plant filled with hot material overnight. In addition, the pressure of the natural gas available was not high and difficulties arose accordingly in heating up the retort to a working temperature within a reasonable period of time.

The retort was filled completely with Beverly stoker coal, sized below one in. and above half in. mesh. The total capacity of the retort was 280 lbs. of coal. In starting up the plant the natural gas burners were lit and inserted in the retort through the observation holes. Owing to the short length of the cooler, air was induced through it into the retort and that portion of the coal in closest proximity to the natural gas flames burned readily. With the coal burning as well as undergoing carbonization, when the extractor came into operation, the char removed from the plant was in an incandescent condition.

In order to provide against this occurrence, efforts were made to restrict the flow of air through the cooler by fitting dampers in the chimney flue. Also, finer size of coal was employed in the hope that this would restrict the amount of air finding its way up through the material in the cooler. In addition, a one quarter inch brass tube with perforations in its under side was inserted just above the cooler so that water could be directed on to the two streams of char. None of these measures were effective in cooling the char to the point at which it would not easily

ignite and again become incandescent on exposure to air.

In one test period immediately before extraction of material commenced, measurement of temperature in the coal bed showed that at a point about 12 inches below the outlet of the gas burners, the coal temperature was 614°C. and 36 inches higher it was 648°C. The flue temperatures T7 and T8 at that time were 710°C. and 330°C. respectively. About 25 minutes after char extraction commenced, the flue gas temperatures had fallen to 500°C. and 240°C. respectively and 15 minutes later the flames from the ignited volatile matter expired. The char removed from the retort during the whole period from the commencement of extraction to the time when the flames in the flues expired, was in an incandescent condition.

In a second test, after a period of six hours required for heating up the retort with natural gas, efforts were made by reducing the rate of extraction of the char to reduce its temperature on removal from the cooler but the material was still incandescent. On this occasion the flue gas temperature varied from 450°C. to 330°C. and the coal temperatures, as measured by T5 fell as much as 100°C. over a period of one hour. These temperatures are given as indicating that even a substantial reduction in the temperature of the char within the retort was insufficient to give the material at the extractor, the temperature which was sufficiently low to prevent its active combustion taking place when it was exposed to the atmosphere.

Up to this stage operation had been quite intermittent. After each day's run the retort was emptied completely and allowed to cool. One test was made to determine if plant operation could be continued from day to day after a shutdown overnight so that a much shorter period for heating the retort with natural gas would be necessary at the start of the following day's run. Accordingly the retort was left fully charged overnight with the dampers of the flues entirely closed and the extractor exit sealed with plugs of thoroughly-wetted and compressed paper. After standing overnight, the temperatures T5 and T6 respectively were 284°C. and 350°C. The following morning the paper plugs were removed, the dampers opened and the natural gas burners lighted. Observation of the ignition of the volatile matter had been taken formerly as an indication that the plant had reached the operating conditions at which the extraction of the char might be commenced. On this particular occasion, however, no such ignition occurred, even after prolonged heating with natural gas, the coal presumably having already lost the bulk of its volatile matter. It was considered that to operate the char extractor at this stage would only result in cold coal being brought into the heated zones which would, of course, simply give rise to conditions similar to those which obtained when the retort was worked intermittently from day to day.

When a charge of dried coal was used it was found that the temperature at which the volatile matter ignited could be attained after a heating period of three instead of six hours. Under these conditions with an air

supply of 40 c.f.m. the average flue gas temperature was 580°C. Working the retort at this temperature for any considerable length of time, however, caused the motor which drove the exhauster to overheat. When the exhauster was shut down, a positive pressure developed in the combustion flues, the gas found its way through the coal hopper and into the room and it became necessary to again shut down the plant. The incandescent condition of the char on extraction necessitated the excessive use of the water spray. This, together with additional water used in quenching the emerging char, gave rise to considerable mechanical difficulties. The rake failed completely to remove the wet material and simply ploughed ridges through it.

In order to overcome the difficulty of the overheating of the exhauster, the pipe to the exhauster was extended and cooled with a water spray/ and a three inch diameter exit pipe of the exhauster replaced by one of six inches diameter. In addition the number of rakes on the discharge mechanism was increased to seven and steam was used for quenching the char in the cooler in place of the water used previously. The steam was admitted through several small tubes introduced at the base of the extractor. Whilst the cooler on the exhaust system was found to be efficient, the char as it came out of the plant was still at a temperature at which it readily ignited on exposure to air.

At this stage of development, it was decided that the fire hazard with the plant in its then location was too great and accordingly the whole plant was dismantled

and reassembled on a more convenient site in the Boiler Room of the University Power Plant. The opportunity was taken to make further modifications in the design of the plant. The cooler was redesigned to provide a greater cooling surface by extending its length, the superficial area being increased from 1770 to 3400 square inches and volume from 2380 to 4200 cubic inches.

The rake form of extractor was replaced with one of a rotary compartmented type. The form of the extractor and the manner of driving it is shown in Figure XVI.

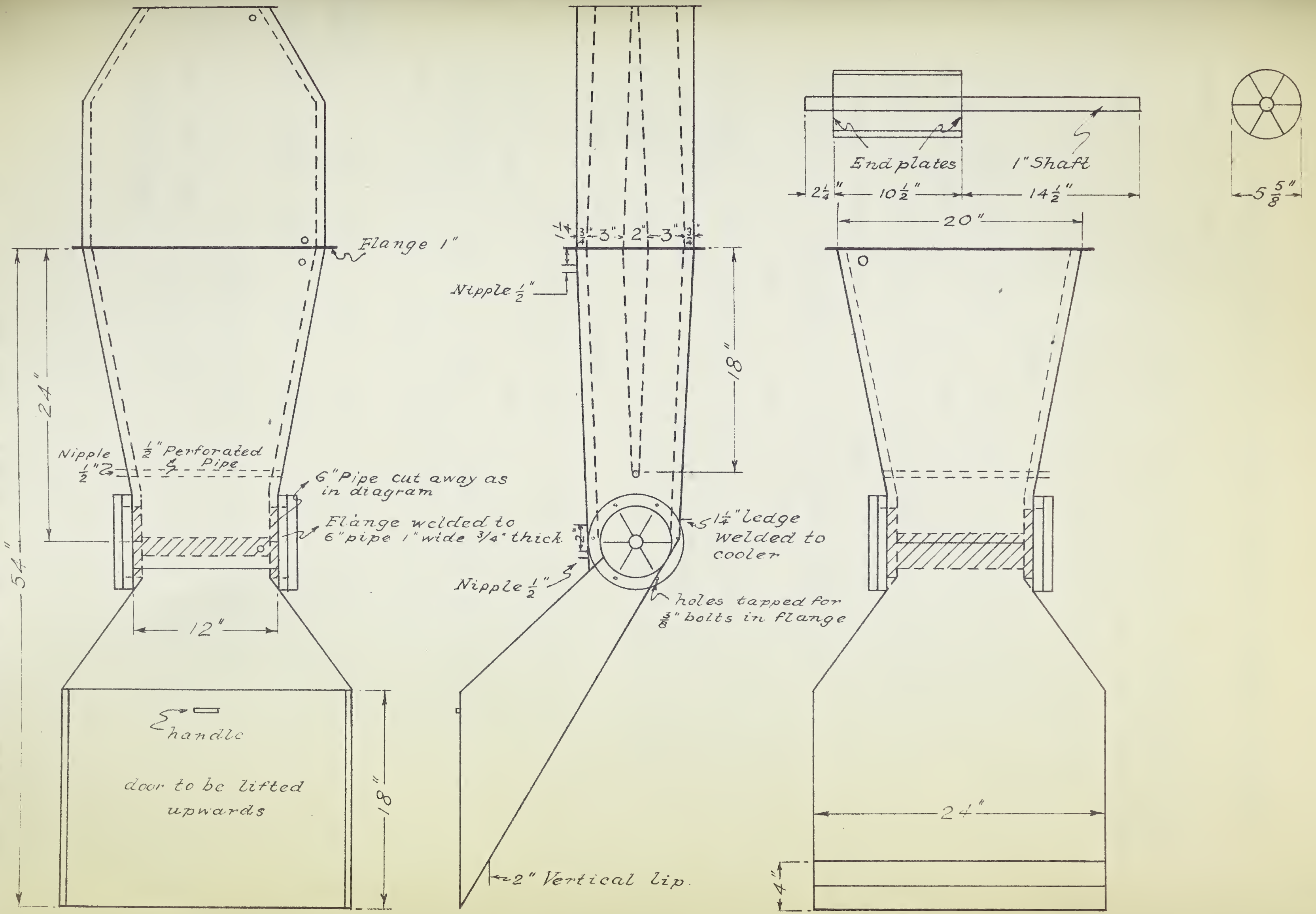
The new site required the installation of a six inch diameter galvanized flue pipe 30 feet in length to convey the gases to the exhauster, which was conveniently situated near to the main stack of the University Power Plant. The cooling surface of the pipe was such that it became possible to discard entirely the water cooler fitted previously to the plant. To provide for any condensate from the cooled flue gases a condenser trap was provided between the exhauster and the retort just prior to the gases entering the exhauster.

The pressure of the natural gas stream now available was considerably greater than formerly. Accordingly, the natural gas burners to the retort were fixed permanently in a horizontal position in the flues, approximately three feet above the base of the flues, nearly level with the lowest air inlet. Holes were drilled in the casing of the retort to make it possible to light-up the natural gas burners more easily. No provision was made for measuring the gas used,

FIGURE XVI

Diagram of Rotary Compartmented Extractor

COOLER AND DISCHARGE MECHANISM.



but the volumes burned were considerably in excess of those employed formerly.

For the purpose of charging the retort with coal, a platform was erected to give easy access to the coal hopper at the top of the retort and the coal was elevated from floor level to the hopper in buckets raised by hand by means of a rope and pulley. In order to reduce the heat loss due to radiation, the outer case was lagged with sheets of asbestos board cut to size and molded to the shape of the retort. These sheets were fixed in position by means of cheese cloth impregnated with a flour adhesive.

A coal bin was constructed to hold about 8 tons of coal. This quantity of coal was screened to pass a one inch mesh screen, so that during carbonization the flow of material would not cease due to any large pieces of coal resting between the baffle plates.

In starting up the plant, the natural gas burners were lighted the night prior to the day's run and were left burning for about 15 hours. By next morning typical temperatures along the length of the retort were as follows:

T.C. Number	T1	T2	T3	T4	T5	T6	T7	T8
Temp. °C.	894	934	1155	1054	558	57	770	770

It will be seen that the temperature at the base of the flues (T6) was only a little above the normal room temperature.

At the commencement of a run the retort was filled entirely with coal, the extractor being stationary with the whole charge of coal resting on it. Almost immediately after charging, volatile matter was observed to fire in the vicinity of the burners. As soon as this occurred, the supply of natural gas was turned off and extraction commenced at a predetermined rate. At the same time the air blower was started, the rotameter adjusted to give the desired air rate and the exhauster turned on.

The exhauster speed could not be varied. With changes in the rate of the air supply, pressures in the retort could not be maintained constant. Some infiltration of air through the cooler occurred even though the length of the cooler had been extended, producing, as in former cases, a char which fired upon exposure to air. Accordingly, a six inch square hole was cut in the exhauster pipe on the retort side of the system and this hole was fitted with a movable cover plate so that the pull of the exhauster of the retort could be controlled.

A positive pressure was desirable in the flues of the retort to guard against infiltration of air into the system and also in order to give the maximum length of time for contact of hot combustion products with the coal charge. Unfortunately, with a slight positive pressure at the top of the retort, it was found that the vapours passed through the coal hopper into the room. Accordingly, the pressure at the top of the flues of the retort was adjusted to a negative pressure of 0.03 ins. water gauge.

Settings of the opening on the exhaust pipe were determined for these pressure conditions and for suitable rates of air flow as measured by the rotameter.

At the outset, Beverly slack coal was employed since supplies of it were then readily available; this coal being used at the site for steam raising purposes. No particular flow difficulties were encountered in using this slack coal in its normally dry condition. On one occasion, however, the coal delivered was superficially wet and when this wet material was used it was found that it would not flow freely through the retort. This particular batch of coal was sampled, precaution being taken against any water loss. Determination of the water contents of this sample and of a sample of the coal as usually delivered in the dry condition, showed that whereas the wet coal contained 27 per cent. of water the water content of the dry material was 25 per cent. This relatively small difference requires emphasis, since it shows that a relatively small amount of water held superficially by the coal may give rise to very considerable operating difficulties in a plant of this kind. It was found moreover, that when blockage of the retort occurred, since it was clearly undesirable to clear the passage by rodding because of possible damage to the structure of the retort, the only satisfactory way of clearing the retort was to heat it with natural gas to a sufficiently high temperature and then to provide ample supplies of air to burn out the char choking the retort.

At a later stage, a supply of Black Diamond slack coal was received. This coal has a much more glossy appearance than Beverly coal and it flowed more freely through the retort. Black Diamond coal in a wet condition, however, caused a like blockage of the coal passage in the retort.

Beverly slack coal was in use on the first occasion on which the plant operated over a complete working day of about eight hours. The proximate analysis and calorific value of Beverly slack coal is given in Table XIII.

Table XIII

Proximate Analysis and Calorific Value of Beverly Slack Coal

	Per Cent.
Moisture	25.6
Ash	10.9
Volatile Matter	25.6
Fixed Carbon	37.9
	100.0
Calorific Value, B.t.u. per lb.	8,200

Observations of the temperatures numbered respectively T1 to T6 from the top to the bottom of the retort, and of the flue gas temperatures, T7 and T8 were made at half-hourly intervals between 9:00 a.m. and 4:00 p.m. To maintain the retort in operation, both the rate of air supply and the rate of discharge were varied from time to time.

A record of the observations made is given in Table XIV together with remarks referring to changes which were found necessary to maintain the retort in operation.

Table XIV

Record of Run on January 3, 1947
using Beverly Slack Coal

	Time after charging, Hours						
	½	1	1½	2	2½	3	3½
T.C. Number	Temperature °C.						
1	319	443	298	288	280	179	98
2	268	402	266	278	209	212	159
3	177	595	751	678	626	588	485
4	702	951	842	788	817	798	759
5	364	560	814	780	740	737	742
6	30	30	708	780	766	747	744
7	338	415	444	426	426	482	449
8	376	482	521	510	482	482	300
Air supply c.f.m.	40	40	40	40	40	40	40
Setting on Discharge Mechanism	-	6	10	10	10	10	10
Pressures, inches water gauge. P_1	-.2	-.32	-.28	-.30	-.30	-.32	-.32
P_2	-.3	-.34	-.27	-.29	-.31	-.31	-.31

	Time after charging, Hours					
	4	4½	5	5½	6	6½
T.C. Number	Temperature °C.					
1	91	96	105	214	197	177
2	137	142	182	254	256	236
3	464	546	560	541	649	607
4	837	792	800	901	773	810
5	906	834	851	896	778	764
6	754	737	732	711	725	740
7	399	438	471	449	452	449
8	304	333	333	373	410	426
Air supply c.f.m.	20	25	25	25	25	25
Setting on Discharge Mechanism	8	8	5	5	8	8
Pressures, inches water Gauge. P_1	-.46	-.36	-.38	-.38	-.30	-.33
P_2	-.45	-.37	-.37	-.37	-.30	-.33

Remarks:

The retort had been heated for 16 hours with natural gas prior to commencement of run.

9:00 a.m.	The air supply was adjusted to 20 c.f.m. Thermocouple 7 had burned out and was replaced.
9:40	The retort was charged with 280 lb. coal and the air increased to 40 c.f.m.
9:55	It was observed that the volatile matter was burning in only one flue.
10:10	The exhauster was started at a slow rate with the extractor dial setting at 6 but a half hour later this was increased to 10.
10:40	The natural gas was turned off and the coal gas was found to be burning readily in both flues. Charging of the retort continued at approximately hourly intervals.
1:00 p.m.	It was observed that the flue temperatures were falling rapidly and in an effort to maintain the flue temperatures the extraction rate was decreased from setting 10 to 8 to 5 and the air rate changed from 40 to 20 to 25 c.f.m. according to the combustion conditions observed.

During the last 2 1/2 hours of the run the weight of the coal carbonized was 295 lb. and the weight of the char produced was 144 lb. giving a yield of 48.8 per cent. By measuring the number of filled buckets of coal processed and char produced a rough approximation of the volume ratio was found to be 1.5 to 1.

The analysis of the char produced is given in Table XV.

Table XV

Analysis of Char from Beverly Slack Coal	
Proximate Analysis	Per cent.
Ash	21.5
Volatile Matter	7.8
Fixed Carbon	70.7
	100.0
Calorific Value, B.t.u. per lb.	11,470

V. TRIAL RUNS

All experimental work described hereafter was carried out on Black Diamond slack coal, in a superficially dry condition, as normally delivered from the mine. The screen analysis, proximate and ultimate analyses and calorific value of this coal are given below. According to the A.S.T.M. classification it is a C type subbituminous coal.

Table XVI

Screen analysis of Black Diamond Slack Coal

Size	Per cent.
-14 mesh	25.4
-8+14 mesh	16.1
-4+ 8 mesh	20.8
-3+ 4 mesh	12.1
-.525 in. + 3 mesh	23.2
-.742 in. + .525 in.	2.3
	100.0

Table XVII

Proximate and Ultimate Analyses and Calorific Values of Black Diamond Slack Coal used in Experiments

Proximate:

	Per cent. (as received)	Per cent. Dry, MM free
Moisture	24.9	
Ash	10.8	
Volatile Matter	26.1	39.6
Fixed Carbon	38.2	60.4
	100.0	100.0
Calorific value, B.t.u. per lb.	8,210	13,000

Ultimate:

	Per cent. (as received)	Per cent. Dry, MM free
Carbon	47.9	75.8
Hydrogen	3.2	5.1
Nitrogen	1.3	1.8
Sulphur	0.4	0.6
Ash	10.8	
Moisture	24.9	
Difference (Oxygen, undetermined and errors)	11.5	16.7
	100.0	100.0

A. Series 1

A series of six runs was carried out at an average coal throughput of 92 lb. per hour. During the first three runs the air supply as measured by the rotameter was maintained at 20 c.f.m., and in the next three runs at 7, 30 and 0 c.f.m. respectively. In the last case no air was supplied by the blower, only such air being available as could infiltrate through leaks in the retort.

Shortly after the commencement of carbonization, the extracting mechanism was started in order to obtain as soon as possible reasonably steady conditions of carbonization. The termperature readings in the coal stream as measured by the thermocouples fluctuated as much as 30 to 50 degrees over a period of a minute. Three readings were, therefore, taken of the temperatures registered by each thermocouple at intervals of one minute and these results averaged to give the half-hourly readings. The pressures P_1 and P_2 were maintained as closely as possible at -.03 and -.10 inches of water respectively. In each run the char was bulked and sampled and the proximate analysis and calorific value determined.

The plant operated satisfactorily for a working period of about 7 hours. Details of these results are given in Tables XVIII to XXI. Three runs were made at an air rate of 20 c.f.m. to see how closely the results would check under the same operating conditions. Since the results obtained were considered to be reasonably reproducable, only the mean of these three runs is presented for an air rate of 20 c.f.m.

Figure XVII shows the variations of flue gas temperature with time. With air supplied only through such leaks as occurred in the setting, that is with the exhauster fan in operation, but the air inlet fan stationary, one hour after charging the retort the flame in one flue slowly expired although the flame in the other flue was maintained till the end of the test, the total period of the test being 5 hours.

It was observed that whereas the flame in the former case at the commencement of the run was of a turbulent nature and completely filled the flue, as time went on the degree of turbulence lessened and the flame slowly retreated from the wall to the baffles. Ultimately there appeared to be a thin sheet of flame along the baffle wall and eventually the flame became patchy and ultimately these patches diminished in size and the flames died completely. In experiments to be described later, it was noted that when the flame in one flue expired the temperature in the other flue increased, for a time at least.

Table XVIII

Trial Run No. 2 — March 17, 1947.
Coal throughput 85 lb. per hour — Air Rate 20 c.f.m.

Time after charging, Hours

T.C. Number	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
	Temperature °C.					
1	565	570	650	560	510	520
2	500	500	500	570	500	580
3	680	730	750	740	730	720
4	780	760	725	705	695	680
5	680	675	650	740	740	705
6			440	475	460	480
7	508	530	540	546	545	540
8	508	530	540	546	545	540

T.C. Number	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7
1	560	610	520	470	460	450	410
2	480	465	490	540	590	540	380
3	700	685	680	685	695	685	660
4	675	675	660	645	640	635	635
5	740	705	680	670	670	705	630
6	505	505	490	480	482	480	480
7	535	530	525	508	498	480	460
8	535	530	525	508	498	480	460

Remarks:

Yield of Char: 48 per cent.
Char sample No. 609-47

Proximate Analysis of Char

	Per cent.
Ash	21.4
Volatile Matter	6.1
Fixed Carbon	72.5
	100.0

Calorific Value, B.t.u. per lb. 11,390

Air - Coal Ratio: 14.1 cu. ft. air per lb. coal.

Table XIX

Trial Run No. 4 — March 25, 1947.
Coal throughput 100 lb. per hour — Air Rate 7 c.f.m.

T.C. Number	Time after charging, Hours: $1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
	Temperature °C.					
1	516	468	192	159	147	140
2	485	403	329	234	194	246
3	608	612	656	676	616	602
4	820	854	812	802	768	785
5	659	822	849	815	778	780
6	110	556	607	654	---	---
7	527	488	510	499	499	493
8	527	488	510	499	499	493

T.C. Number	$4\frac{1}{2}$	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$	7
1	124	127	117	108	102	98
2	112	76	74	60	64	62
3	560	514	481	460	440	424
4	768	737	737	747	730	754
5	735	790	742	750	768	764
6	---	---	621	652	621	633
7	493	499	516	488	510	488
8	493	499	516	488	510	488

Remarks:

Yield of Char: 48 per cent.
Char sample No. 611-47
Air - coal Ratio: 4.2 cu. ft. per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	21.5
Volatile Matter	6.8
Fixed Carbon	71.7
	100.0

Calorific Value, B.t.u. per lb. 11,540

Table XX

Trial Run No. 5 — March 27, 1947.
Coal throughput 86 lb. per hour — Air Rate 30 c.f.m.

T.C. Number	Time after charging, Hours: ½	1	1½	2	2½	3	3½
	Temperature °C.						
1	475	490	495	480	420	360	350
2	415	505	490	540	495	425	380
3	750	790	785	780	735	680	700
4	710	675	685	670	660	660	630
5	495	565	570	620	625	635	600
6	90	420	525	530	535	550	520
7	666	715	720	705	660	600	643
8	666	715	720	705	660	600	643

T.C. Number	4	4½	5	5½	6	6½	7
1	390	380	360	360	365	400	400
2	440	453	420	426	405	572	560
3	715	705	690	690	680	682	690
4	635	624	615	605	605	643	630
5	600	590	610	586	595	654	675
6	510	508	495	508	495	490	490
7	620	632	605	605	630	610	620
8	620	632	605	605	630	610	620

Remarks:

Yield of Char: 53 per cent.
Char sample No. 612-47
Air - coal ratio: 20.9 cu. ft. air per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	21.4
Volatile Matter	6.8
Fixed Carbon	71.8
	100.0

Calorific Value, B.t.u. per lb. — 11,510

Table XXI

Trial Run No. 6 March 28, 1947.

Discharge Setting as in other runs of this series.
No air supplied by blower.

T.C. Number	Time after charging, hours.				
	½	1	1½	2	2½
	Temperature °C.				
1	610	497	510	416	240
2	500	410	540	492	350
3	530	614	740	747	720
4	750	716	785	770	805
5	105	433	625	685	665
6	25	62	410	501	525
7	620	645	500	445	380
8	620	645	690	710	740

T.C. Number	3	3½	4	4½	5
1	202	145	142	130	152
2	310	230	259	100	122
3	698	630	525	520	492
4	788	750	728	725	716
5	652	740	737	780	754
6	546	560	553	530	483
7	340	280	210	170	110
8	760	765	775	775	785

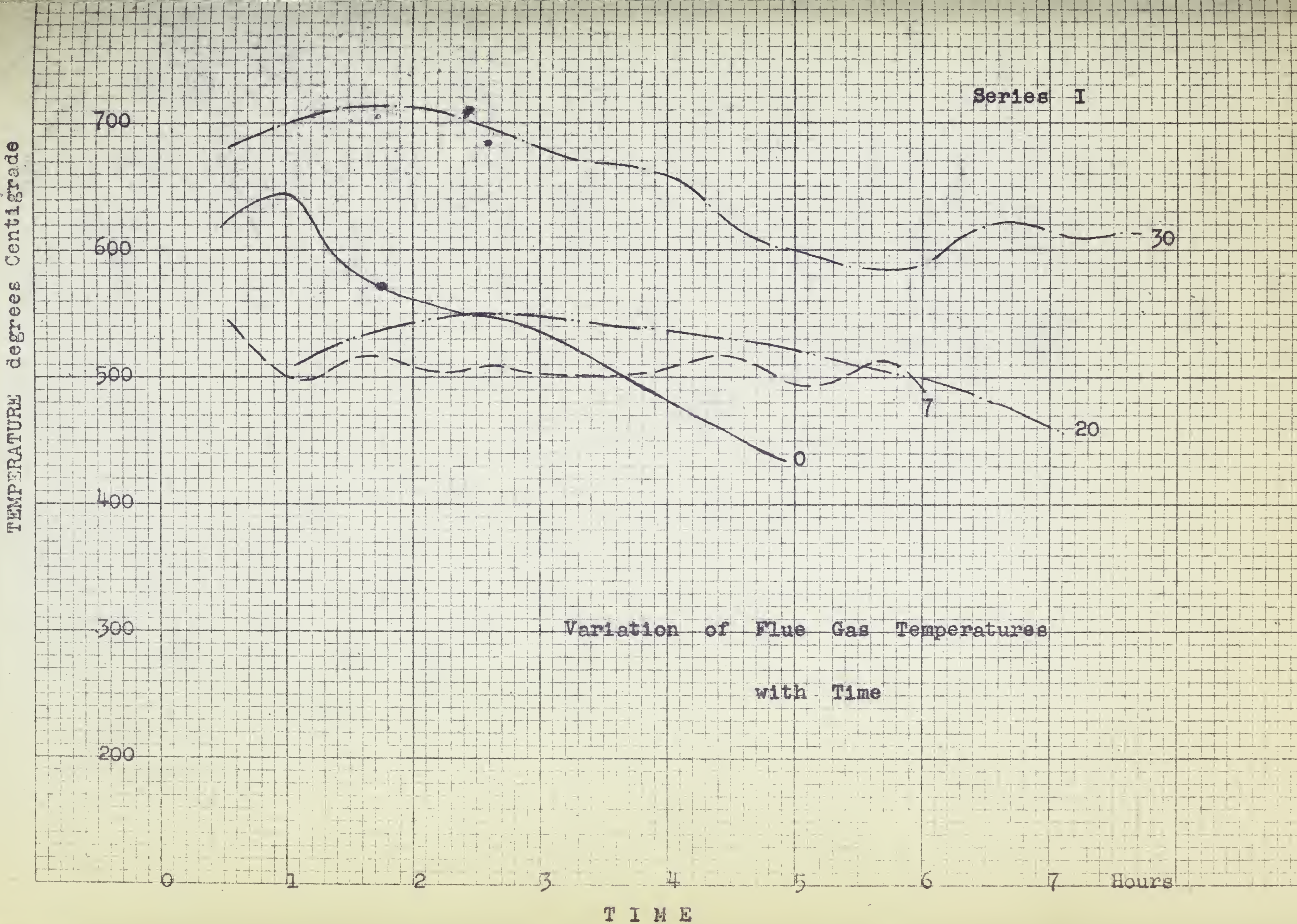
Remarks:

The flame in one flue expired after four hours operation. The run was continued for another hour but no sample was taken and the rate of throughput was not determined.

It is considered, therefore, not unreasonable to represent the flue gas temperature in this instance in Figure XVII by the average of the temperatures shown by thermocouple 7 and 8, as in cases where the flue temperatures over the whole period of operation were approximately parallel and only about 20°C. apart as a maximum. Figure XVII indicates that the general tendency is for the flue gas temperature to increase as the rate of air supply increases. When the combustion of the volatile matter is complete, an increase in air supply infers a proportionate increase in the volume of the flue gas and with a higher flue gas temperature there is then a greater loss of heat up the stack and hence a smaller amount of heat expended in drying and carbonizing.

Figures XVIII to XXIII show the variations of the temperature in the coal stream as measured by thermocouples T1 to T6 during the carbonization period. Only when the rates of air supply are low, i.e. curves 0 and 7 is it possible to indicate even approximately where drying ceases and carbonization commences. Under these conditions drying of the coal by hot gases prior to carbonization is seen in Figure XVIII and to a lesser extent in Figure XIX. Even under these conditions incipient thermal decomposition seems to be evident in the early stages of carbonization, before the flow of fresh coal through the retort has given rise to a state approaching steady conditions, that is

FIGURE XVII



Series I
700
600
500
400
300
200
TEMPERATURE degrees Centigrade
30
20
7
0
0
1
2
3
4
5
6
7
Hours
T I M E
Variation of Flue Gas Temperatures
with Time

FIGURE XVIII

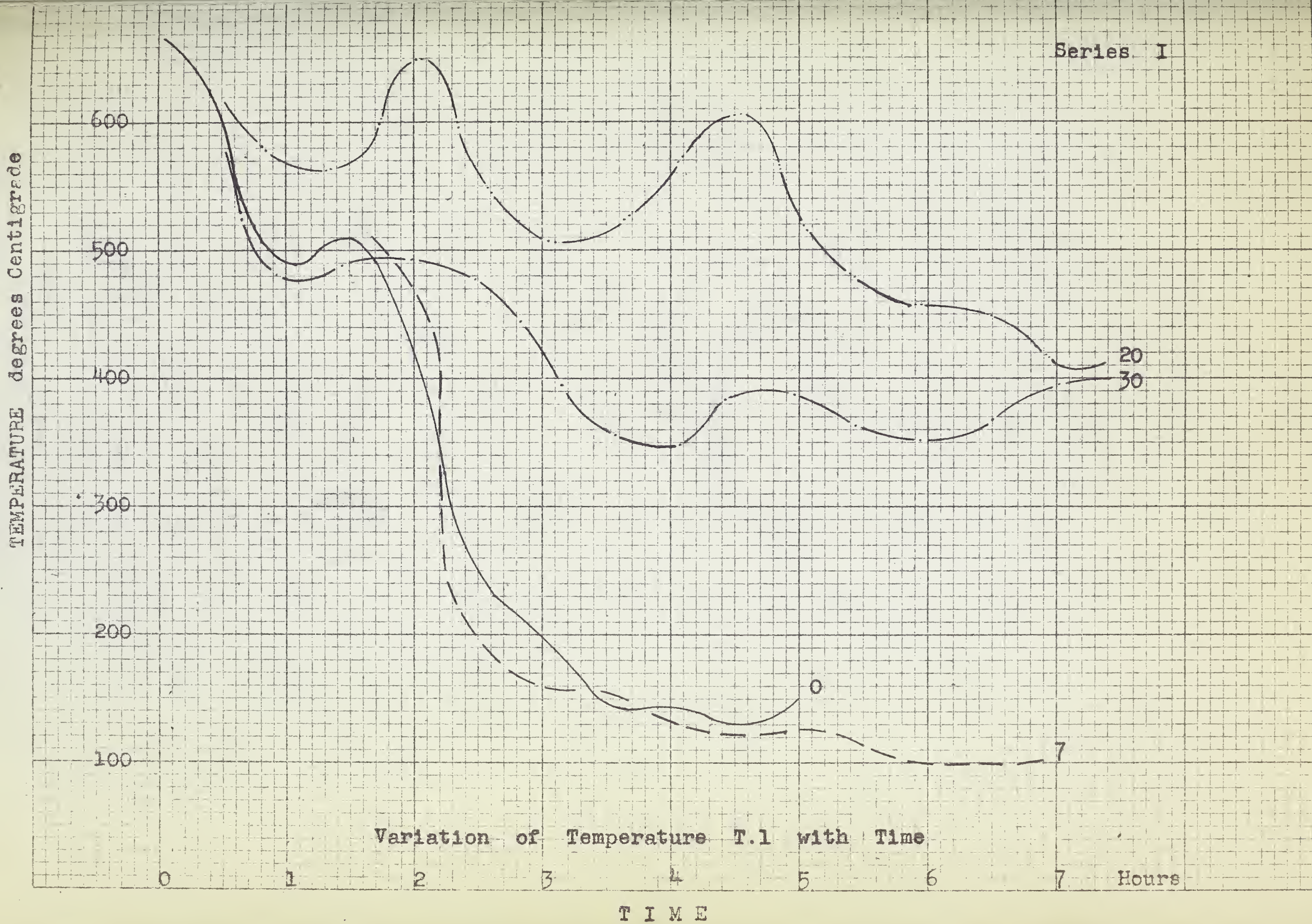

Series I
600
500
400
300
200
100
TEMPERATURE degrees Centigrade
0
1
2
3
4
5
6
7
Hours
20
30
0
7
Variation of Temperature T.1 with Time
T I M E

FIGURE XIX

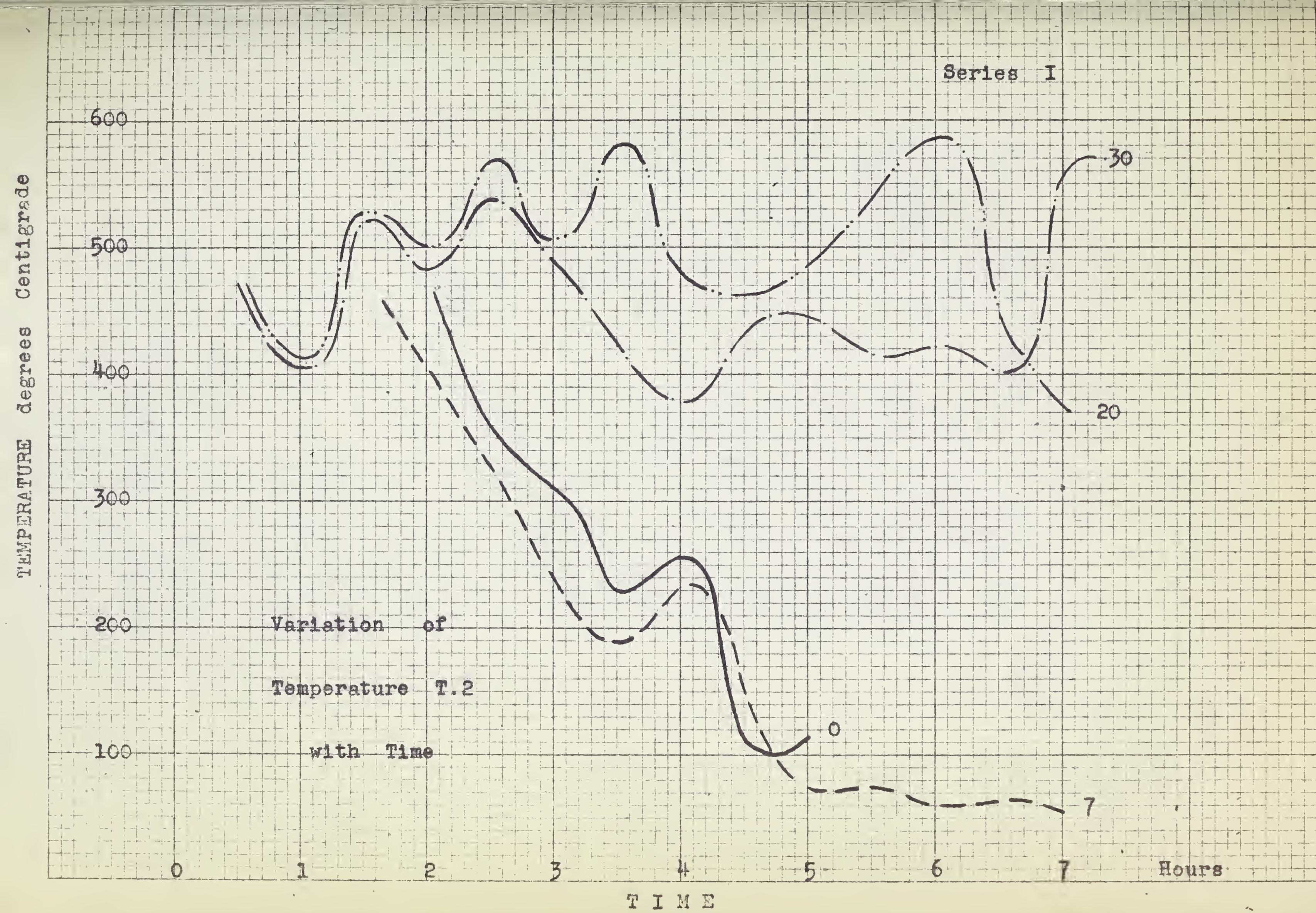
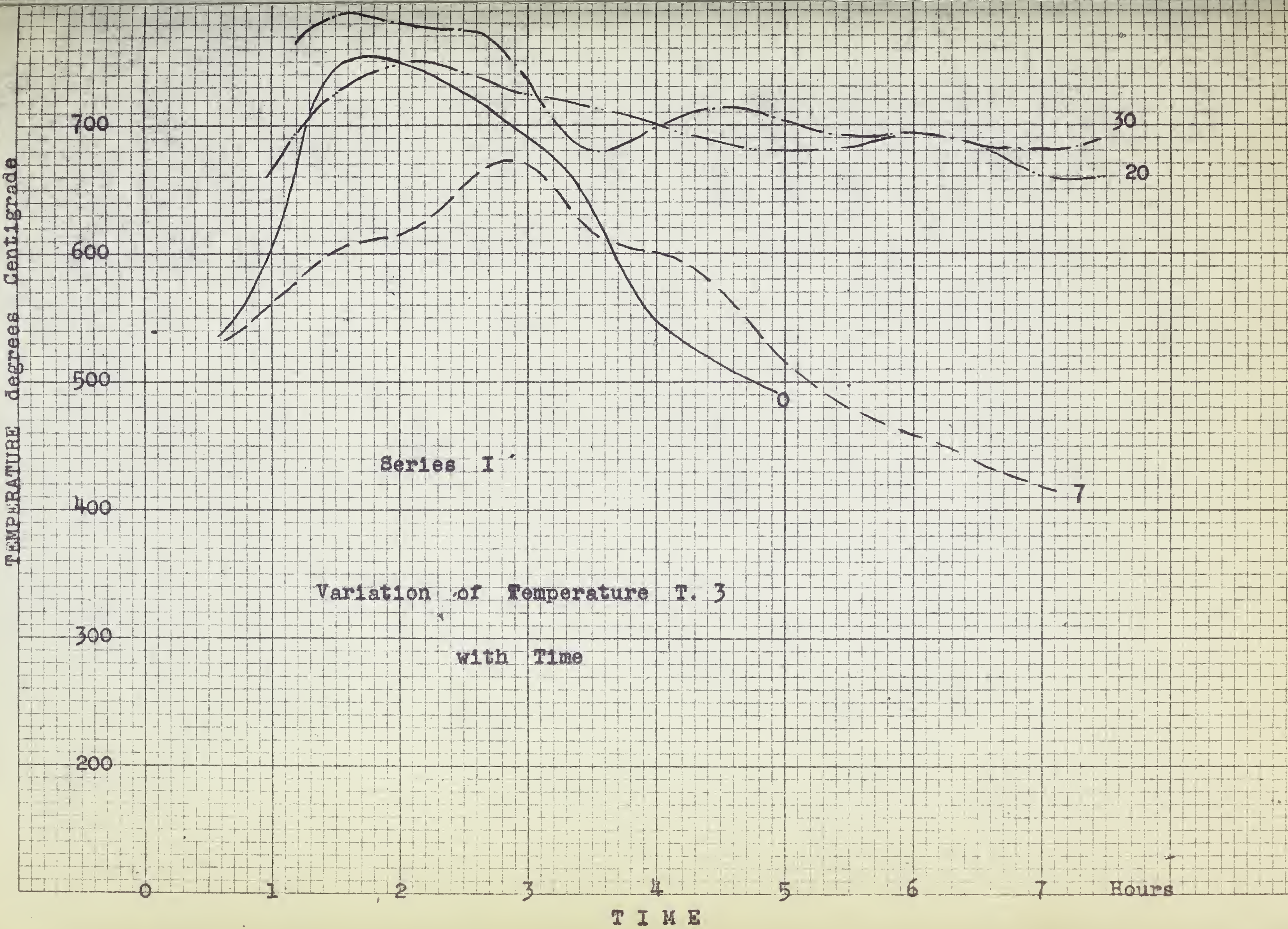

Series I
600
500
400
300
200
100
TEMPERATURE degrees Centigrade
30
20
0
7
Variation of
Temperature T.2
with Time
0
1
2
3
4
5
6
7
Hours
T I M E

FIGURE XX



Series I
Variation of Temperature T. 3
with Time
TEMPERATURE degrees Centigrade
700
600
500
400
300
200
0
1
2
3
4
5
6
7
Hours
TIME
30
20
0
7

FIGURE XXI

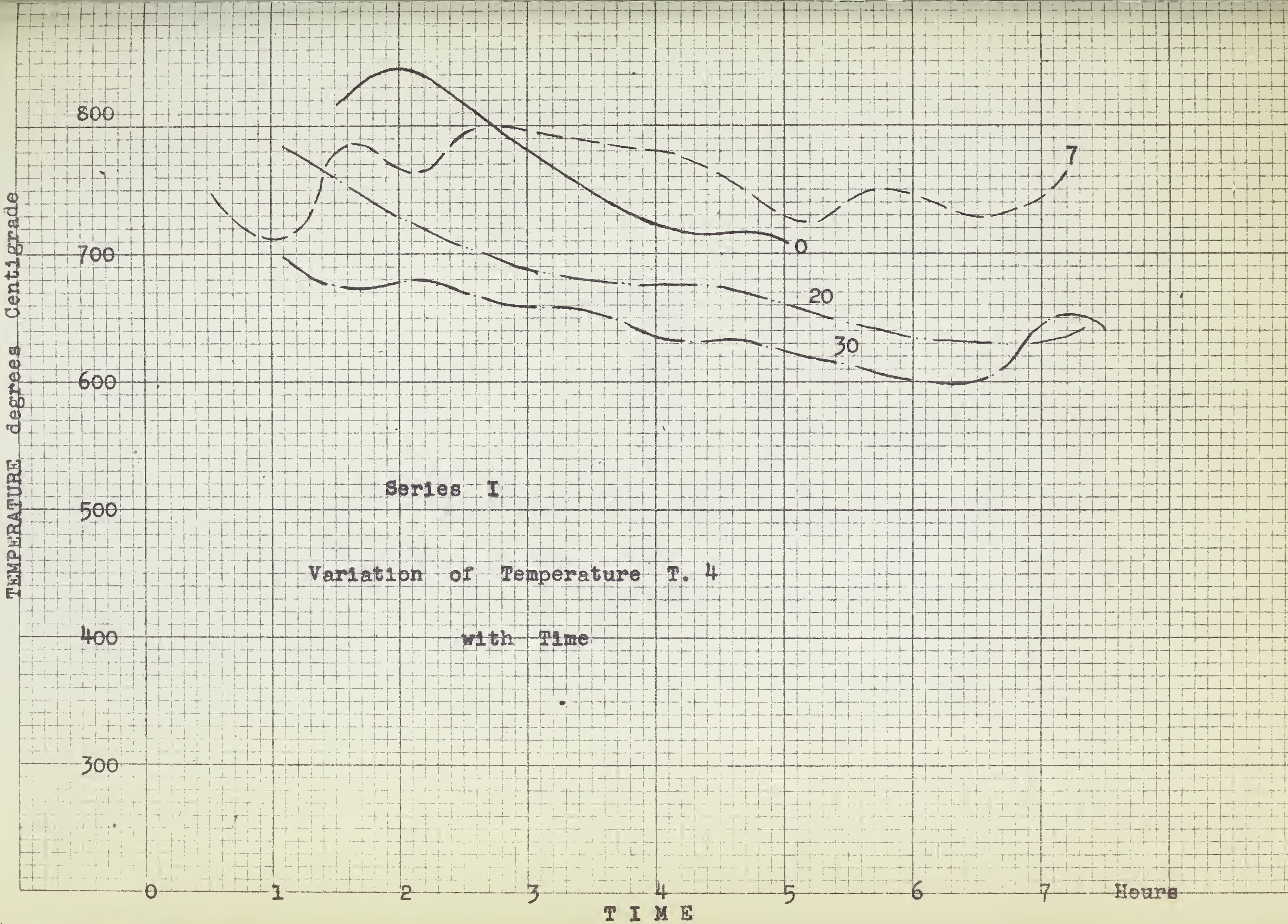

Series I
Variation of Temperature T. 4
with Time
TEMPERATURE degrees Centigrade
800
700
600
500
400
300
0
1
2
3
4
5
6
7
Hours
TIME
0
7
20
30

FIGURE XXII

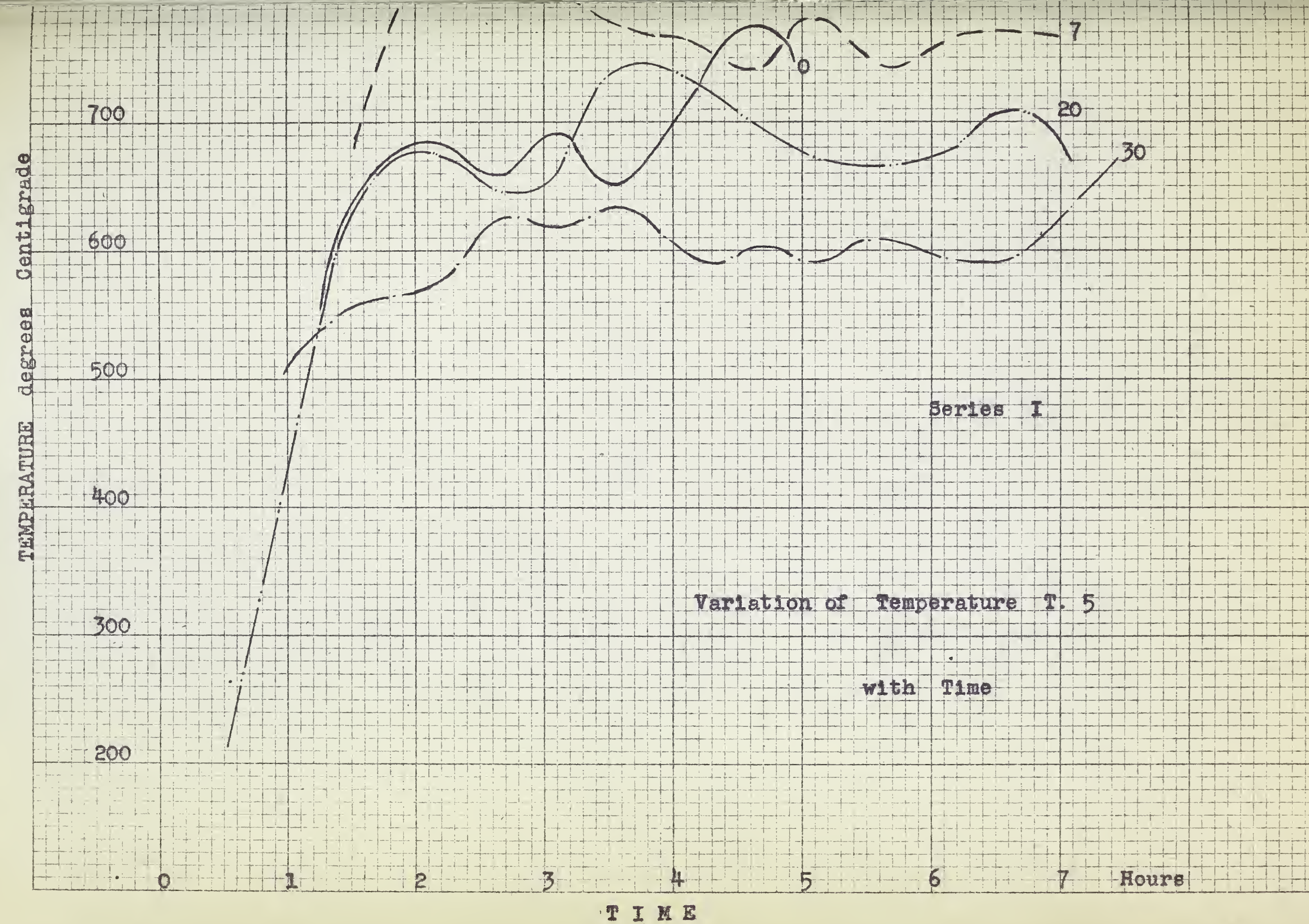
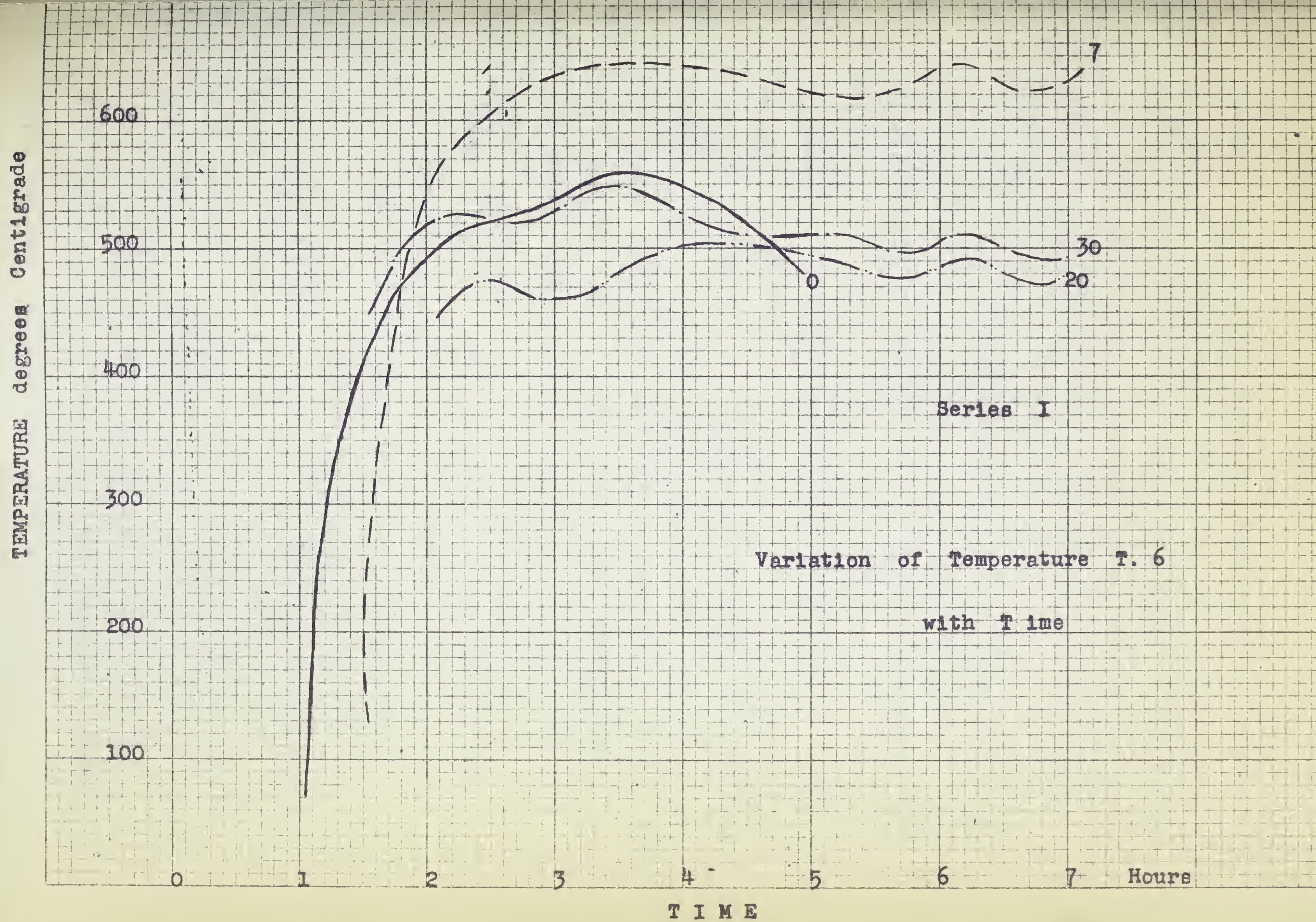

Series I
Variation of Temperature T. 5
with Time
TEMPERATURE degrees Centigrade
200
300
400
500
600
700
0
1
2
3
4
5
6
7
Hours
T I M E
7
0
20
30

FIGURE XXIII



Series I
Variation of Temperature T. 6
with T ime
7
30
20
0
600
500
400
300
200
100
0
1
2
3
4
5
6
7
Hours
TIME
TEMPERATURE degrees Centigrade

as represented by the curves in Figure XVII becoming parallel to the time axis. With these rates, the drying zone apparently extended at least five feet into the retort. A further two feet down the retort carbonization of the coal had obviously set in with the attainment of temperatures exceeding 700°C.

No precise explanation can be attempted of the nature of the temperature variations which are shown in the curves for all thermocouples up to T4 and most marked in T2 in the first three to five hours of operation of the plant. Hollings and Cobb (16) have shown that in coals of a high oxygen content exothermic reactions are most marked when coal is carbonized at low temperatures, that is from 280 to 480°C. owing to the thermal decomposition of oxygenated compounds. Since with particles of considerable size carbonization takes an appreciable time, temperatures of this order may be considered to obtain in the interior of the particles even though the exterior may attain temperatures of 700°C. These exothermic effects must continue during carbonization over a considerable length of the retort and to develop in a perfectly regular manner.

Carbonization of the material with the low rate of air supply of seven c.f.m. appears to continue well past thermocouples T5 and T6, that is well into the equalizer zone and it appears that in the equalizer zone at a slow rate of air supply cooling of the material is not very rapid.

As is to be expected and as shown by the analysis of the char, the greater the proportion of the

heat available in the carbonization and drying processes, the greater the actual degree of carbonization. Thus with 20 cubic feet of air per minute the yield of char is 48 per cent. and the char has a volatile matter content of 6.1 per cent. whereas with 30 c.f.m. the yield is 53 per cent. and the volatile matter content of the char is 6.8 per cent. With an air rate of 7 cubic feet per minute, a high yield of char was obtained and this result could only be ascribed, at this state, as due to incomplete combustion of the volatile matter.

Summarizing as shown by this series of experiments,

1. Steady conditions of operation of the plant are approached only after the retort has been in operation at least three to five hours.
2. In the initial period of three to five hours, the passage of the fresh coal down the retort and the varying size of the material may account for the variations in the temperatures measured along the length of the retort.
3. These temperature variations, however, develop quite uniformly as the material passes through the retort. Their occurrence makes it impossible to differentiate clearly the drying and carbonizing zones except at the lowest air rates.
4. With a throughput of 92 lbs. of coal per hour, the optimum air supply is of the order of 20 c.f.m. Above and below this supply, larger quantities of heat are lost in the flue gases, either as sensible or undeveloped heat.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

B. SERIES II

A series of ten trial runs was made with an average throughput of 157 lbs. of coal per hour whilst the air rate was varied from 20 to 50 c.f.m. Mechanically, the discharge mechanism operated quite efficiently at this rate and, as far as was noted, the char was not discharged at any appreciably higher temperature than at the lower rate employed in Series I. In general, operation continued much as in the first series of trial runs.

The temperature readings during this series of runs and the proximate analysis and calorific values of the chars are given in Table XXII to XXXI. The results are expressed graphically on the same basis as previously in Figures XXIV to XXX. The graphs represent averages of two or more runs at the same air rates.

In Figure XXV the temperature curve indicated by thermocouple T1 for runs at 20 c.f.m., represents substantially the normal conditions in the drying process. The onset of carbonization is only perceptible. At 40 c.f.m. at the position in the retort represented by T1 carbonization phenomena became quite pronounced. At 50 c.f.m. the drying conditions again become apparent as in the case with 20 c.f.m. The curves in Figure XXV take up the position which would be anticipated and these curves correlate with those in Figure XXIV which show the average flue gas temperatures. It should be noted that the curve for 50 c.f.m. in Figure XXIV whilst not indicating pronounced carbonization

TABLE XXII

Trial Run No. 7 — April 2, 1947.
Throughput 144 lbs. per hour — Air Rate 20 c.f.m.

Time after Charging, Hours

T.C. Number	½	1	1½	2	3	3½
	Temperature °C.					
1	665	390	305	220	175	160
2	520	410	305	270	180	170
3	505	710	675	630	605	570
4	570	720	695	665	670	640
5	110	570	595	620	600	625
6	30	490	520	520	480	490
7	640	590	570	527	482	466
8	640	570	537	493	438	432

T.C. Number	4	4½	5	5½	6	6½
1	160	145	130	130	120	120
2	115	70	60	70	70	60
3	500	450	435	410	435	440
4	595	615	600	600	620	635
5	620	685	625	650	650	685
6	445	470	410	455	480	495
7	437	427	427	421	416	410
8	421	388	377	355	371	377

Remarks:

Both flue temperatures fell rapidly.
Yield of char: 57 per cent.
Char sample No. 613-47
Proximate analysis of Char

	Per cent.
Ash	19.0
Volatile Matter	15.7
Fixed Carbon	65.3
	100.0

Calorific Value, B.T.u. per lb. 11,320

Air - coal Ratio 8.3 cu. ft. air per lb. coal.

TABLE XXIII

Trial Run No. 8 — April 8, 1947.
Throughput 150 lbs. coal per hour — Air Rate 30 c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½	3
	Temperature °C.					
1	310	320	295	250	230	205
2	275	310	405	200	185	160
3	680	760	730	690	710	675
4	784	775	750	710	685	680
5	630	675	680	660	640	660
6	250	575	610	580	530	545
7	650	704	688	654	650	626
8	650	610	621	593	583	571

T.C. Number	3½	4	5	5½	6	6½
1	220	190	185	170	180	165
2	170	120	130	100	110	60
3	680	635	635	640	680	570
4	665	675	665	650	705	675
5	705	695	690	680	705	600
6	575	560	575	615	570	620
7	618	610	599	593	593	577
8	560	543	521	499	510	493

Remarks:

Yield of Char: 53 per cent.
Air - coal ratio 12.0 cu. ft. air per lb. coal.
Char Sample No. 614-47

Proximate Analysis of Char

	Per cent.
Ash	20.2
Volatile Matter	9.1
Fixed Carbon	70.7
	100.0

Calorific Value, B.t.u. per lb. 11,650

TABLE XXIV

Trial Run No. 9 — April 15, 1947.
Throughput 166 lbs. coal per hour. — Air Rate 40 c.f.m.

T.C. Number	1	1½	2	3
	Temperature °C.			
1	405	335	355	280
2	305	270	340	240
3	690	705	705	640
4	650	635	665	620
5	465	550	615	615
6	105	525	540	500
7	690	710	704	627
8	692	714	710	677

Time after charging, Hours

T.C. Number	4	5	6	6½
1	260	250	250	220
2	220	180	170	120
3	620	610	605	610
4	620	620	625	630
5	625	655	640	690
6	505	505	515	550
7	630	630	645	654
8	630	630	582	593

Remarks:

Yield of Char: 55 per cent
Char sample No. 615-47
Air - coal ratio: 14.5 cu. ft. air per lb. coal

Proximate Analysis of char

	Per cent.
Ash	19.6
Volatile Matter	12.7
Fixed Carbon	67.7
	100.0

Calorific Value, B.t.u. per lb. 11,500

Ultimate Analysis of Char Sample 615-47

	Per cent.
Carbon	70.55
Hydrogen	2.45
Nitrogen	1.20
Sulphur	0.40
Ash	19.60
Moisture	---
Oxygen (by difference)	5.80
	100.00

Net Calorific Value, B.t.u. per lb. 11,280

TABLE XXV

Trial Run No. 10 May 27, 1947.
Coal throughput 170 lbs. per hour. Air Rate 30 c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½
	Temperature °C.				
1	570	340	350	295	260
2	390	395	300	235	155
3	530	705	635	590	595
4	710	720	660	645	586
5	130	555	585	565	430
6	50	450	490	440	430
7	599	566	566	566	566
8	599	667	666	610	566

T.C. Number	3	3½	4	4½	5
1	229	210	205	205	170
2	157	147	160	105	80
3	560	510	490	440	375
4	576	580	580	550	510
5	560	570	580	550	560
6	400	450	480	455	425
7	599	649	649	649	704
8	499	448	426	426	260

Remarks:

Rate of throughput excessive. Flame in one flue went out after five hours of operation.

Yield of Char: 54 per cent.
Char sample No. 616-47
Air - coal ratio: 10.6 cu. ft. air per lb. coal.

Proximate Analysis of Char

	Per Cent.
Ash	17.6
Volatile Matter	17.9
Fixed Carbon	64.5
	100.0

Calorific value, B.t.u. per lb. 11,510

TABLE XXVI

Trial Run No. 11 May 28, 1947.
Coal throughput not determined. Discharge setting such as to give approximately same rate as other runs in Series II.

Air Rate 50 c.f.m.

T.C. Number	Time after charging, Hours $\frac{1}{2}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3
	Temperature °C.					
1	360	345	355	350	310	160
2	105	220	145	170	195	160
3	440	630	580	570	560	405
4	610	640	625	625	620	585
5	480	555	590	610	640	650
6	315	390	490	480	495	390
7	582	649	677	649	666	427
8	582	704	663	649	621	316

Remarks:

Three hours after charging, the flames in one flue had expired and the flame in the other flue was almost out.

Char Sample No. 617-47.

Proximate Analysis of Char

	Per cent.
Ash	17.2
Volatile Matter	17.3
Fixed Carbon	65.5
	100.0

Calorific Value, B.t.u. per lb. 11,560

TABLE XXVII

Trial Run No. 12 — May 29, 1947.
Coal throughput 161 lbs. per hour. — Air Rate 40 c.f.m.

T.C. Number	Time after charging, Hours: ½	1	1½	2	2½	3
	Temperature °C.					
1	560	430	355	325	275	195
2	270	365	260	260	185	105
3	515	670	665	625	585	580
4	685	715	650	640	635	565
5	490	565	695	605	620	550
6	50	450	515	505	515	460
7	649	660	654	649	649	693
8	704	716	654	649	593	388

Remarks:

The flame in one flue was out three hours after discharge commenced. The top plate on the carbonizer was burned through on both sides of the hopper.

Char Sample No. 618-47.

Proximate Analysis of Char

	Per cent.
Ash	19.2
Volatile Matter	14.2
Fixed Carbon	66.6
	100.0

Calorific Value, B.t.u. per lb. 11,560

[illegible]

[illegible]

[illegible]
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]
[illegible]
[illegible]
[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

TABLE XXVIII

Trial Run No. 13 — June 24, 1947.
Coal throughput 157 lbs. per hour. — Air Rate 40 c.f.m.

Time after charging, Hours

T.C. Number	$1\frac{1}{2}$	$2\frac{1}{2}$	$3\frac{1}{2}$	$4\frac{1}{2}$
	Temperature °C.			
1	420	390	270	325
2	310	150	80	130
3	--	--	--	--
4	580	610	650	645
5	490	550	635	660
6	205	500	480	485
7	593	649	593	560
8	649	560	549	638
	5	$5\frac{1}{2}$	6	$6\frac{1}{2}$
1	320	325	300	303
2	120	130	107	170
3	--	--	--	--
4	645	645	600	595
5	670	660	675	685
6	485	485	435	440
7	538	510	466	432
8	621	621	621	638

Remarks:

Yield of Char: 54 per cent.
Char sample No. 619-47
Air - coal ratio 15.3 cu. ft. air per lb. coal

Proximate Analysis of Char

	Per cent.
Ash	16.9
Volatile Matter	16.1
Fixed Carbon	67.0
	100.0

Calorific Value, B.t.u. per lb. 11,580

TABLE XXIX

Trial Run No. 14
Coal throughput 147 lbs. per hour

June 25, 1947.
Air rate 30 c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½	3	3½
	Temperature °C.						
1	500	460	436	407	360	345	350
2	240	160	167	154	90	100	170
3	--	--	--	--	580	535	560
4	725	735	718	680	675	680	680
5	570	645	668	678	675	645	670
6	280	545	604	558	540	540	545
7	704	743	716	666	632	616	604
8	704	704	682	654	632	616	614

T.C. Number	4	4½	5	5½	6	6½
1	340	320	320	315	320	315
2	145	105	105	120	105	75
3	576	545	515	535	540	530
4	675	660	660	670	720	680
5	675	680	680	680	710	705
6	580	560	570	570	580	605
7	604	583	593	593	593	582
8	603	593	593	560	549	538

Remarks:

Yield of Char: 55 per cent.
Char sample No. 620-47
Air - coal Ratio: 12.2 cu. ft. air per lb. coal

Proximate Analysis of Char

	Per cent.
Ash	17.6
Volatile Matter	13.0
Fixed Carbon	69.4
	100.0
Calorific Value, B.t.u. per lb.	11,720

TABLE XXX

Trial Run No. 15 — June 26, 1947.
Coal Throughput 155 lbs. per hour. — Air Rate 20 c.f.m.

T.C. Number	Time after charging, Hours: ½	1	1½	2	2½	3½
	Temperature °C.					
1	535	440	420	360	335	265
2	205	180	180	70	80	--
3	630	750	735	680	595	500
4	700	810	780	725	725	680
5	615	720	700	730	750	714
6	100	575	655	655	650	580
7	639	604	593	543	527	454
8	638	604	549	543	527	454

T.C. Number	4	4½	5	5½	6	6½
1	255	230	195	190	175	165
2	--	--	--	--	--	--
3	475	460	391	340	320	340
4	655	690	626	540	590	570
5	710	721	730	700	680	705
6	610	574	560	505	450	400
7	430	427	416	410	410	410
8	430	427	416	410	410	410

Remarks:

Yield of char: 54 per cent.
Char sample No. 621-47
Air - coal Ratio 7.8 cu. ft. air per lb. coal

Proximate Analysis of char

	Per cent.
Ash	17.6
Volatile Matter	11.9
Fixed Carbon	70.5
	100.0

Calorific Value, B.t.u. per lb. — 11,730

TABLE XXXI

Trial Run No. 16 — June 27, 1947.
Coal throughput 161 lb. per hour. — Air rate 50 c.f.m.

Time after charging, Hours

T.C. Number	$\frac{1}{2}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$
	Temperature °C.			
1	510	440	400	365
2	229	200	75	--
3	750	750	600	560
4	730	725	680	640
5	620	680	660	630
6	400	640	605	540
7	771	771	704	671
8	771	771	700	660

T.C. Number	3	4	$4\frac{1}{2}$	5
1	330	250	245	197
2	--	--	--	--
3	495	390	325	541
4	620	540	550	532
5	625	--	--	--
6	550	505	525	527
7	720	538	516	505
8	600	427	382	260

Remarks:

The flame in one flue expired after five hours operation.

Yield of Char: 59 per cent.
Char sample No. 622-47
Air - coal ratio: 18.6 cu. ft. per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	17.6
Volatile Matter	13.4
Fixed Carbon	69.0
	100.0

Calorific Value, B.t.u. per lb. 11,790

FIGURE XXIV

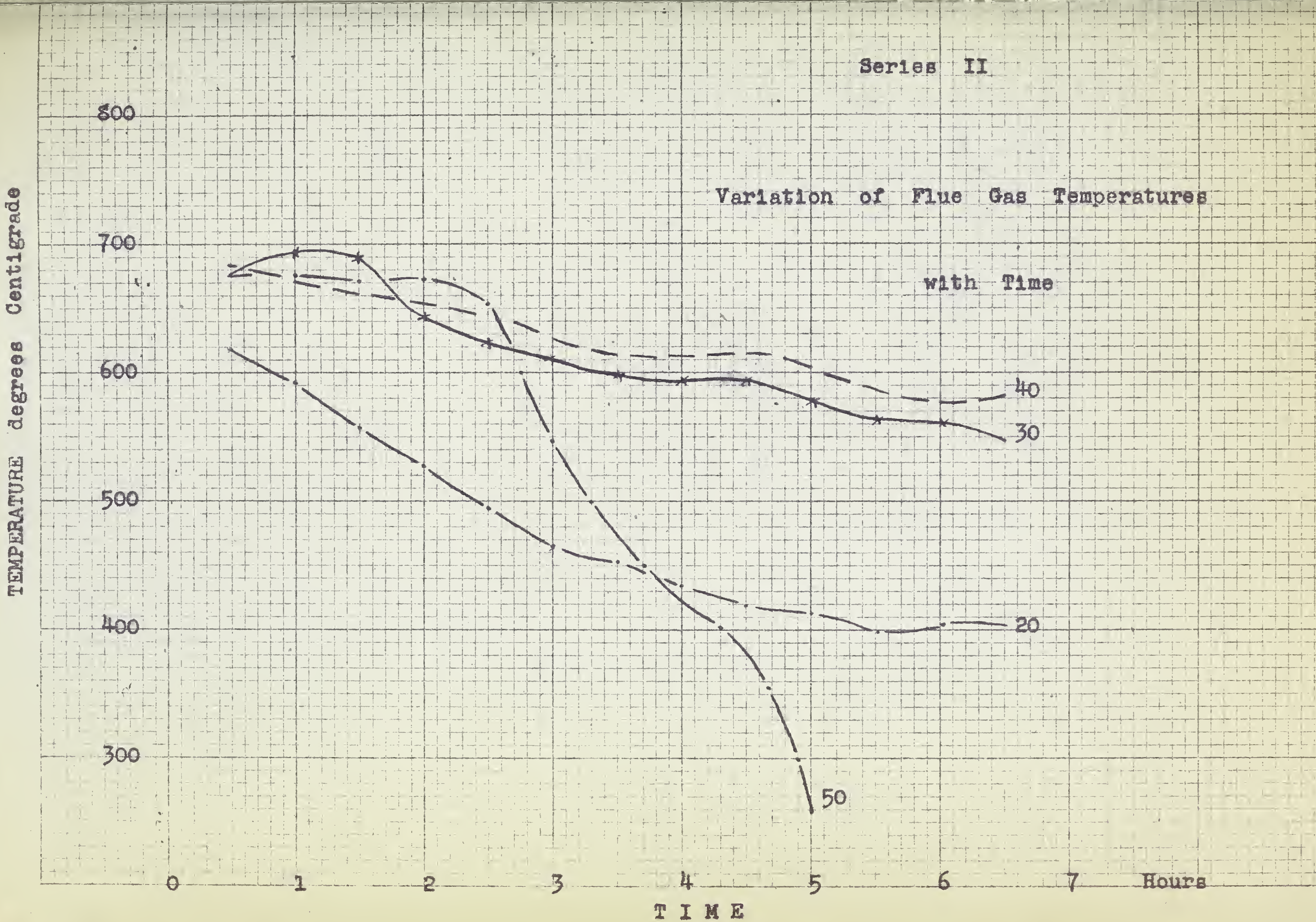

Series II
Variation of Flue Gas Temperatures
with Time
800
700
600
500
400
300
TEMPERATURE degrees Centigrade
0
1
2
3
4
5
6
7
Hours
T I M E
40
30
20
50

FIGURE XXV

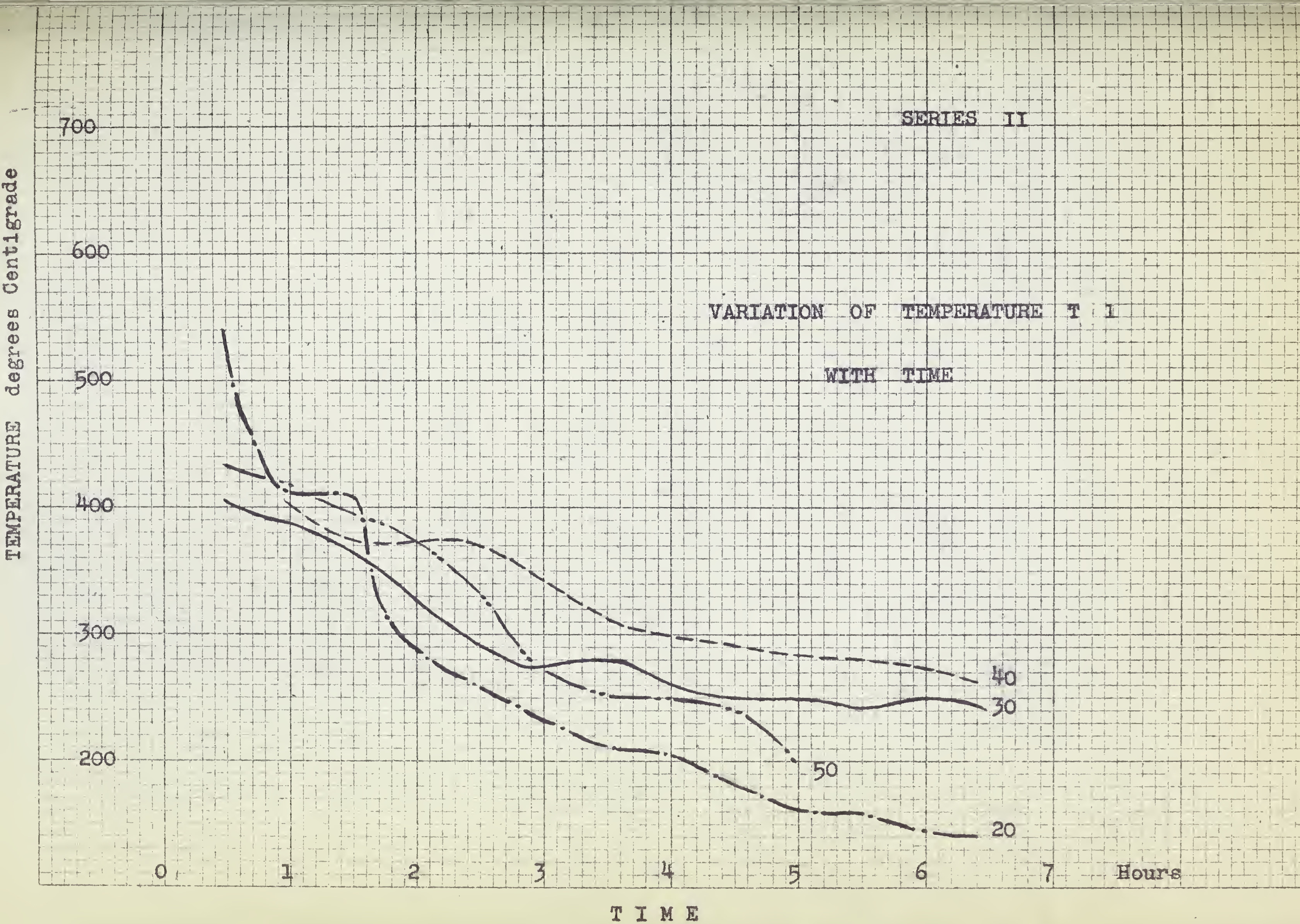

SERIES II
VARIATION OF TEMPERATURE T 1
WITH TIME
TEMPERATURE degrees Centigrade
700
600
500
400
300
200
0
1
2
3
4
5
6
7
Hours
TIME
40
30
50
20

FIGURE XXVI

SERIES II
VARIATION OF TEMPERATURE T.2
WITH TIME
TEMPERATURE degrees Centigrade
600
500
400
300
200
100
0
1
2
3
4
5
6
7
Hours
40
30
20
50
T I M E

FIGURE XXVII

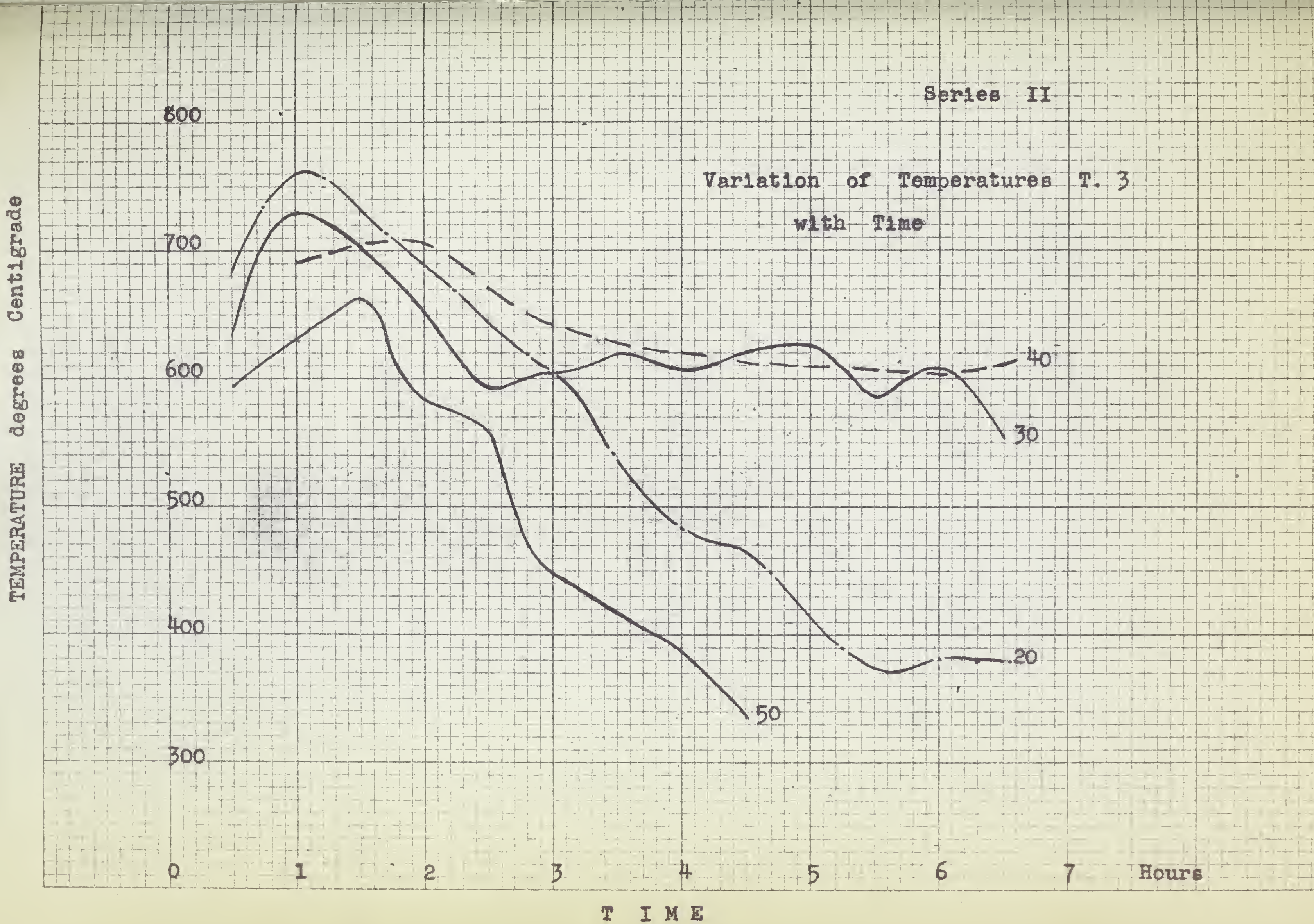
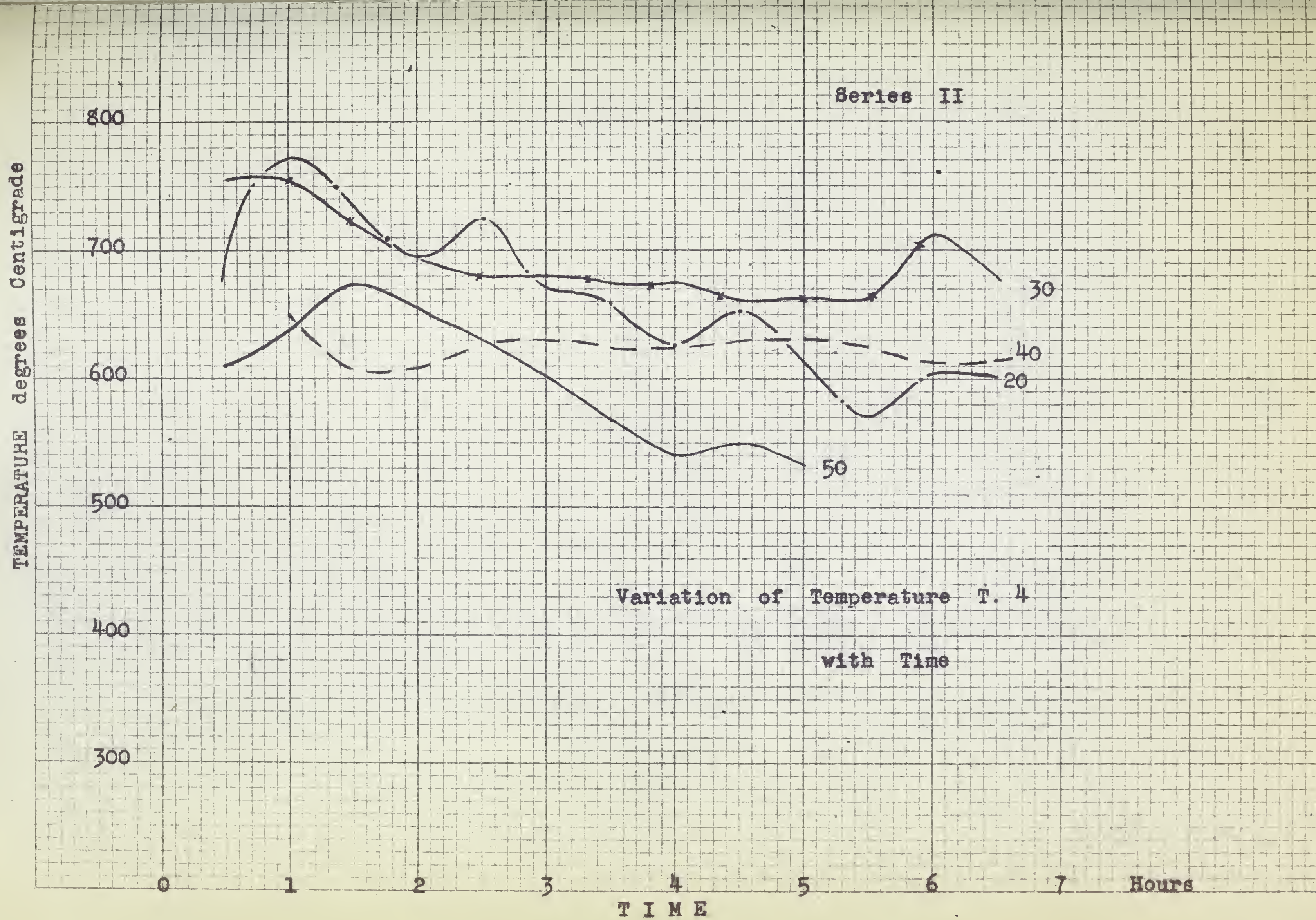

Series II
Variation of Temperatures T. 3
with Time
800
700
600
500
400
300
0
1
2
3
4
5
6
7
Hours
40
30
20
50
T I M E
TEMPERATURE degrees Centigrade

FIGURE XXVIII



Series II
800
700
600
500
400
300
TEMPERATURE degrees Centigrade
30
40
20
50
Variation of Temperature T. 4
with Time
0
1
2
3
4
5
6
7
Hours
T I M E

FIGURE XXIX

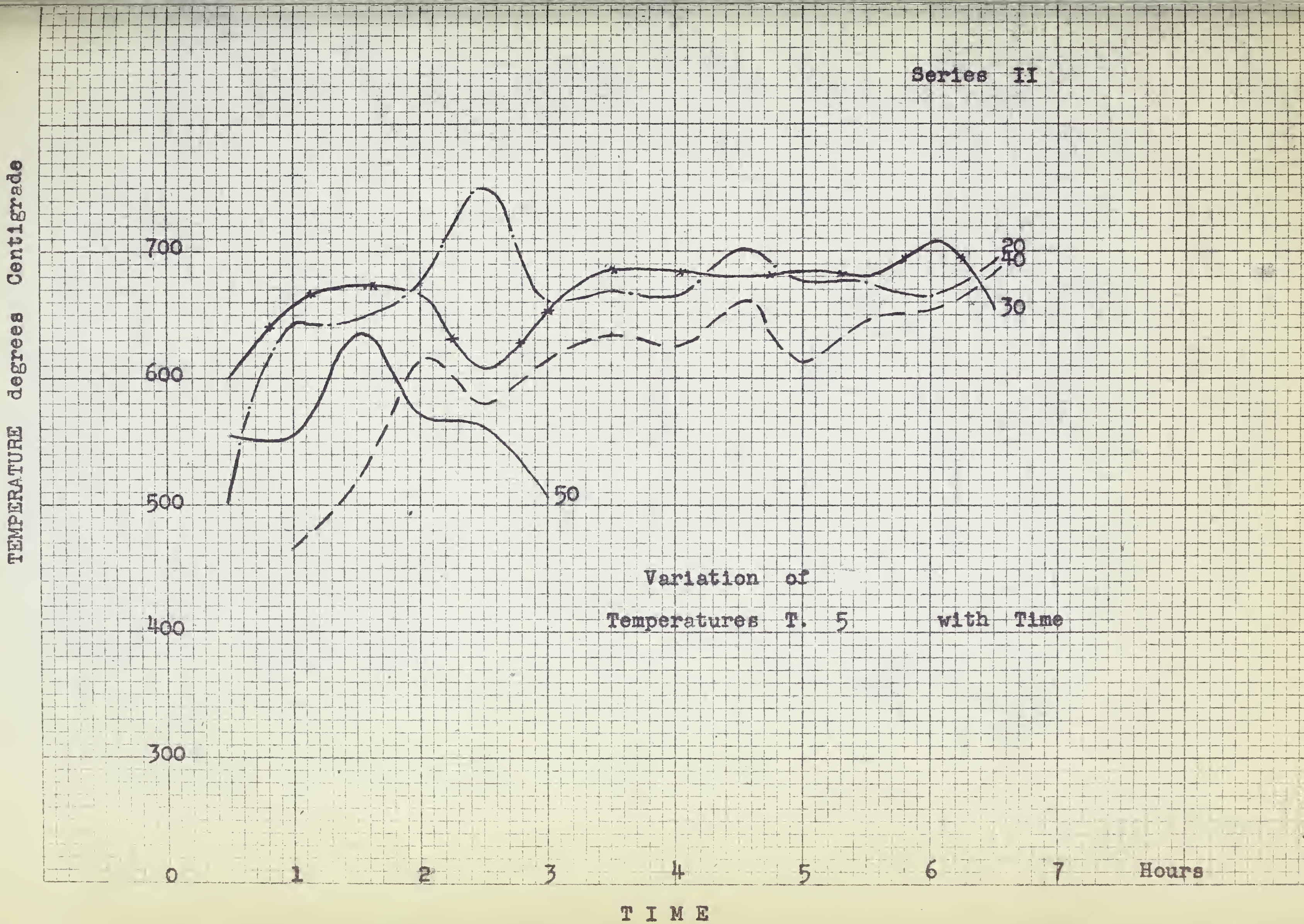
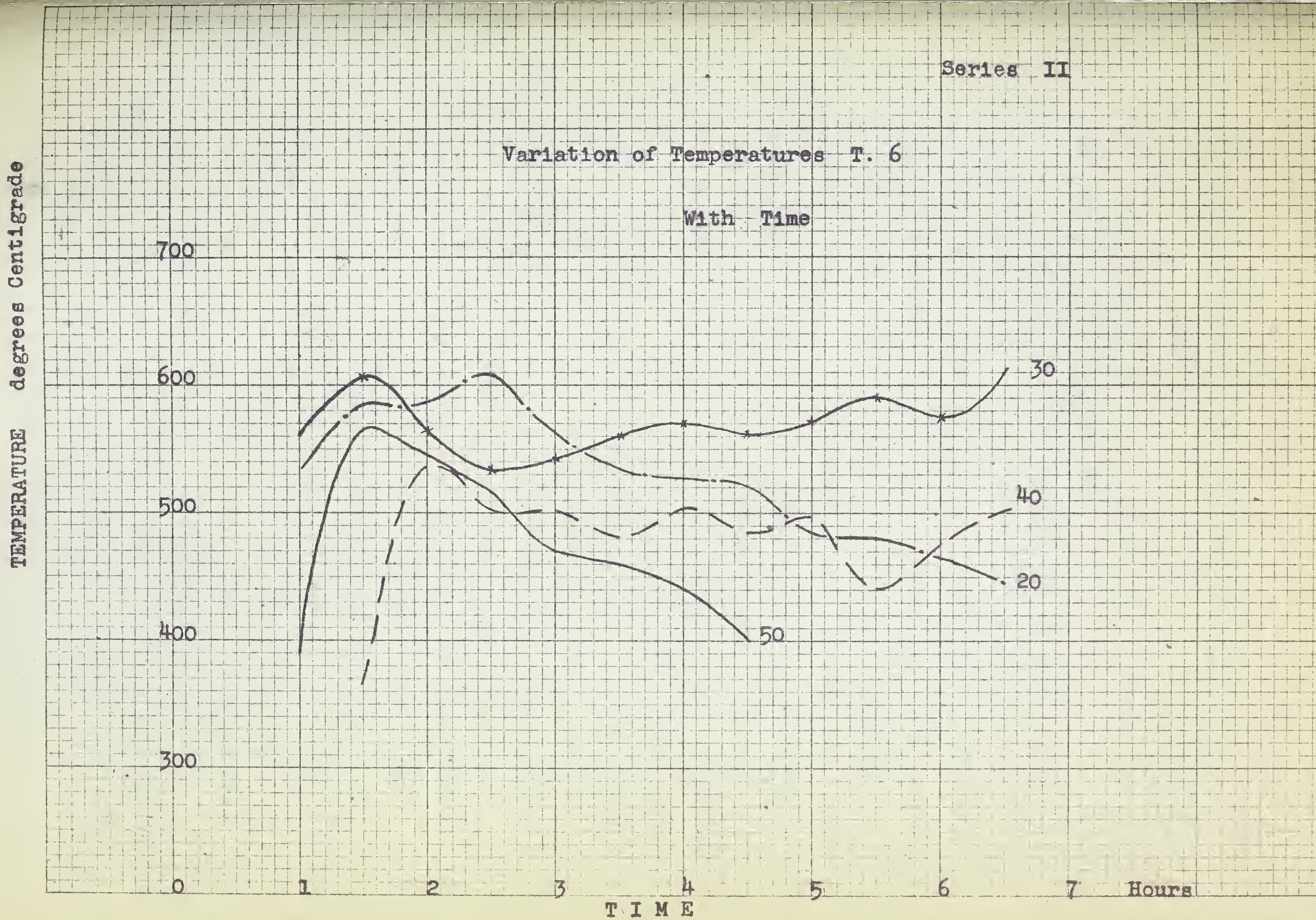

Series II
TEMPERATURE degrees Centigrade
700
600
500
400
300
20
40
30
50
Variation of
Temperatures T. 5 with Time
0
1
2
3
4
5
6
7
Hours
T I M E

FIGURE XXX


Series II
Variation of Temperatures T. 6
With Time
TEMPERATURE degrees Centigrade
700
600
500
400
300
0
1
2
3
4
5
6
7
Hours
T I M E
30
40
20
50

characteristics does show somewhat excessively high temperatures in the initial three hours of carbonization with respect to T1 in Figure XXV as well as with flue gas temperatures in Figure XXIV.

The flue gases in passing out of the retort change direction at the top of the flues and a certain amount of turbulence necessarily occurs here. Invariably in these trial runs, temperature T2 is lower than temperature T1. With the relatively high rate of discharge it is preferable in this series, to assume that the bottom of the drying zone is best approximated from the thermocouple T2. Reference to Figure XXVI shows that at an air rate of 50 cu. ft. per minute, the bottom of the drying zone is somewhat below this position although, as in previous cases, carbonization effects are also observable here. If the curves for the 50 c.f.m. rate are compared with those for the 40 c.f.m. rate, it will be seen that at 40 c.f.m., which relatively represents optimum conditions of operation of this retort at this rate of throughput, the temperatures shown by T2 are much higher in the latter case. With 40 c.f.m., the drying zone appears to be well past the position of thermocouple T2 and the curves for temperatures at T3 show that at this rate, carbonization is well advanced at this position in the retort. At lower and higher rates of air supply, the carbonization zone obviously extends much farther down the retort. Apparently at 50 c.f.m. the amount of excess air is such as to reduce

very substantially the calorific intensity and the rate of heat transfer from the hot gases to the charge in the lower regions of the retort.

In this series of runs, the char was sampled from material obtained in the last hour and one half in each run. One sample, namely that obtained from run 8, with an air supply of 30 c.f.m., shows a low volatile matter content and the yield is correspondingly low. The samples of char obtained in the other runs do not, on the whole, show marked differences. Excluding the former sample, volatile matter contents for rates of 20, 30, 40 and 50 c.f.m. of air are respectively 13.8, 15.4, 14.3 and 15.3 per cent.

Examination of the actual hourly observations, taken during run 8 have not disclosed any particular reasons for the low volatile matter content of the char in this case, but it will be observed in Figures XXV to XXX that particularly in the lower portion in the retort the temperatures were relatively high and that these temperatures were maintained down to the position shown by thermocouple T6. The positions of the thermocouples T5 and T6 are well below the lower level of the air inlets and the readings of these thermocouples indicate conditions after the material had been raised to its full carbonization temperature.

Judging by the volatile matter contents and yields obtained in this series of runs, if the temperatures in the equalizer section of the retort are not too high,

a char can be obtained which contains a relatively high quantity of volatile matter. If, however, these temperatures are somewhat higher the char appears to lose its volatile matter rapidly.

It should be noted that, generally, the volatile matter content of the chars in this series of runs is very much higher than in Series I. It would seem, therefore, that to obtain a char of a high volatile matter content, a high rate of discharge is essential. This applies equally to the yield of char. However, it would be necessary to continue each run for a much longer period of time than about eight hours to determine whether such a high rate could be maintained indefinitely. Initially, the temperatures given the retort by heating with natural gas are so high that sufficient reserve of heat is contained by the retort to maintain a higher throughput than is possible by the process itself. This is evidenced by the general fall in temperatures throughout the retort. The calorific value of the char obtained at both rates is approximately the same.

The optimum air rate as determined by the quantity of coal carbonized, appears to be reasonably in line with the results of the runs in Series I. Whereas in the former case the quantity was 13.0 cu. ft. of air per lb. of coal, in Series II the rate was 15.2 cu. ft. of air per lb. of coal.

C. SERIES III

In speaking of the design of the retort three zones have been distinguished, namely drying and preheating, carbonizing and equalizer zones. When the retort is charged with coal, the retort is already at a relatively high temperature. Before the discharge of the char commences and following the cooling of the retort momentarily, the whole of the coal charge at least above the air inlet commences to dry from the exterior to the interior of the charge and drying is followed almost immediately by carbonization and evolution of the volatile matter.

The volume and composition of the volatile matter vary with the degree of carbonization. When the volatile matter ignites and commences to burn, the rate of drying and of carbonization will increase so long as the heat required for these processes does not exceed the sum of that derived from the combustion of the volatile matter and the heat already available in the heated retort. If the heat required for drying and carbonization is in excess of this sum, then the system will slowly cool and the cooling will continue until a balance is reached between the heat required and the heat generated by the combustion of the volatile matter. In time, if the latter is insufficient for the drying and carbonization of the incoming coal the whole process will eventually cease.

Up to this state no data had been obtained which would allow of even an approximation of the distribution of the available heat generated in the retort.

In this series, six runs were made during which half hourly analyses of the waste gases for carbon dioxide, oxygen and carbon monoxide were carried out systematically using a Hays' modification of the Orsat apparatus. Owing to the variable operation of the discharge mechanism, measurements of the throughput were made over regular intervals following the commencement of the discharge of the char. The period elapsing between the time when the discharge mechanism came into operation and the time when char commenced to be discharged varied, of course, with the throughput of the material. When discharge of material was commenced, coal and not char was, of course, removed from the retort.

(a) In Run 17, the retort having been heated to carbonization temperature and then filled with coal, heating with natural gas was continued for one half hour, after which time the gas was turned off and the discharge mechanism started. Although in the initial period of a run, uncarbonized and later, partially-carbonized material is discharged, it is possible by measuring the rate of discharge at this time to make a reasonable approximation of the rate of discharge which will be obtained over still later periods of operation. In this instance a measure of the rate of discharge during the first 55 minutes after turning off the gas indicated a rate of throughput of 180 lbs. of coal per hour, which is some 20 lbs. per hour in

excess of that desired. At the end of the 55 minutes, therefore, the discharge was stopped. After a period of 20 minutes to allow of necessary adjustment of conditions in the retort the discharge was again started at a lower rate, which on measuring over the next 40 minutes was found to be 161 lbs. per hour which was approximately the rate desired. This rate was maintained throughout the remainder of the test while the discharge was in operation.

Experience having shown that when the flue gas temperature commenced to fall rapidly, the period during which the retort would operate further was very limited. After three hours of operation, the average flue gas temperature having fallen from 820°C. to 600°C., it was decided at this stage to discontinue the discharge of the char and to raise the flue gas temperature by again heating the retort with natural gas. After a period of one hour the flue gas temperature had risen to 860oC. At this stage the bulk of the volatile matter in the coal had been driven off and burned, the remaining volatile matter being insufficient to maintain operating temperatures. It was, therefore, decided to again commence discharging the char and to turn off the supply of natural gas. Thereafter the carbonizer was allowed to run without further alterations to the discharge rate. It will be seen that shortly after the recommencement of discharging, the temperatures of the flue gases responded slightly owing, presumably, to

larger quantities of combustible gases from the coal burning in the retort flues. Table XXXII and Figure XXXI show the results obtained in this run .

As will be seen from Figure XXXI, 4 3/4 hours after the discharge was fixed at approximately 160 lbs. per hour, the flue gas temperatures had fallen rapidly to 330°C., the flame in one flue had expired and the flame in the other one was on the point of expiring.

Figures XXXII and XXXIII show the relationship of the carbon dioxide and the temperature respectively, to the oxygen contents of the waste gases. Referring to Figure XXXII it will be seen that a fair number of points fall below the curve which has been drawn as representing substantially complete combustion of the gases in the retort. The curve cuts the axis at 15 per cent. carbon dioxide and, of course, 21 per cent. oxygen. The points falling below this curve represent conditions where either the retort was heated with natural gas or where over one per cent. of carbon monoxide was present in the flue gases.

In the combustion of a fuel, a diminishing carbon dioxide content in the combustion gases is indicative of increasing quantities of excess air. Accordingly, in order to obtain a high thermal efficiency efforts must be made to control combustion conditions so as to maintain a high carbon dioxide content in the combustion gases and at the same time as low a flue gas temperature as possible,

[illegible]

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[illegible]

TABLE XXXII

Trial Run No. 17 — December 30, 1947.
Throughput 161 lbs. per hour — Air Rate 40 c.f.m.

	Time after charging, Hours						
	½	1	1½	2	2½	3½	4
T.C.Number	Temperature °C.						
1	572	421	364	320	396	292	392
2	364	544	407	341	392	292	433
3	600	--	--	--	--	--	--
4	726	815	752	656	565	504	612
5	167	541	659	619	516	501	454
6	40	90	669	602	494	518	416
7	820	765	825	765	770	680	730
8	820	765	800	765	750	600	730
	Percentage in flue gases						
Carbon Dioxide	10.2	11.0	7.0	6.8	8.4	7.0	9.2
Oxygen	6.2	3.0	10.4	11.8	9.6	11.6	6.6
Carbon Monoxide	1.4	2.4	1.4	0.6	0.8	0.4	1.2

	Time after charging, Hours					
	4½	5	5½	6	6½	7
T.C. Number	Temperature °C.					
1	623	431	326	296	288	264
2	702	490	362	307	296	268
4	796	754	650	614	565	548
5	490	678	619	604	562	548
6	390	690	604	572	544	518
7	840	820	760	750	715	710
8	850	820	760	710	660	610
	Percentage in flue gases					
Carbon Dioxide	9.8	7.6	5.8	11.0	11.0	9.8
Oxygen	5.6	10.6	12.2	6.0	6.4	8.2
Carbon Monoxide	0.6	0.6	1.0	1.2	1.0	0.8

	Time after charging, Hours					
	7½	8	8½	9	9½	10
T.C. Number	Temperature °C.					
1	234	214	198	179	164	148
2	244	232	222	200	177	148
4	520	510	473	448	398	294
5	537	532	497	490	445	307
6	516	513	452	438	407	307
7	710	660	620	570	570	410
	Percentage in flue gases					
Carbon Dioxide	8.8	8.8	7.4	6.8	6.0	1.4
Oxygen	9.2	9.6	11.2	12.2	13.2	18.8
Carbon Monoxide	0.8	0.6	0.8	0.8	0.8	0.4

Remarks:

Metal thermocouple guard at T3 fused preventing replacement of burned out thermocouple.

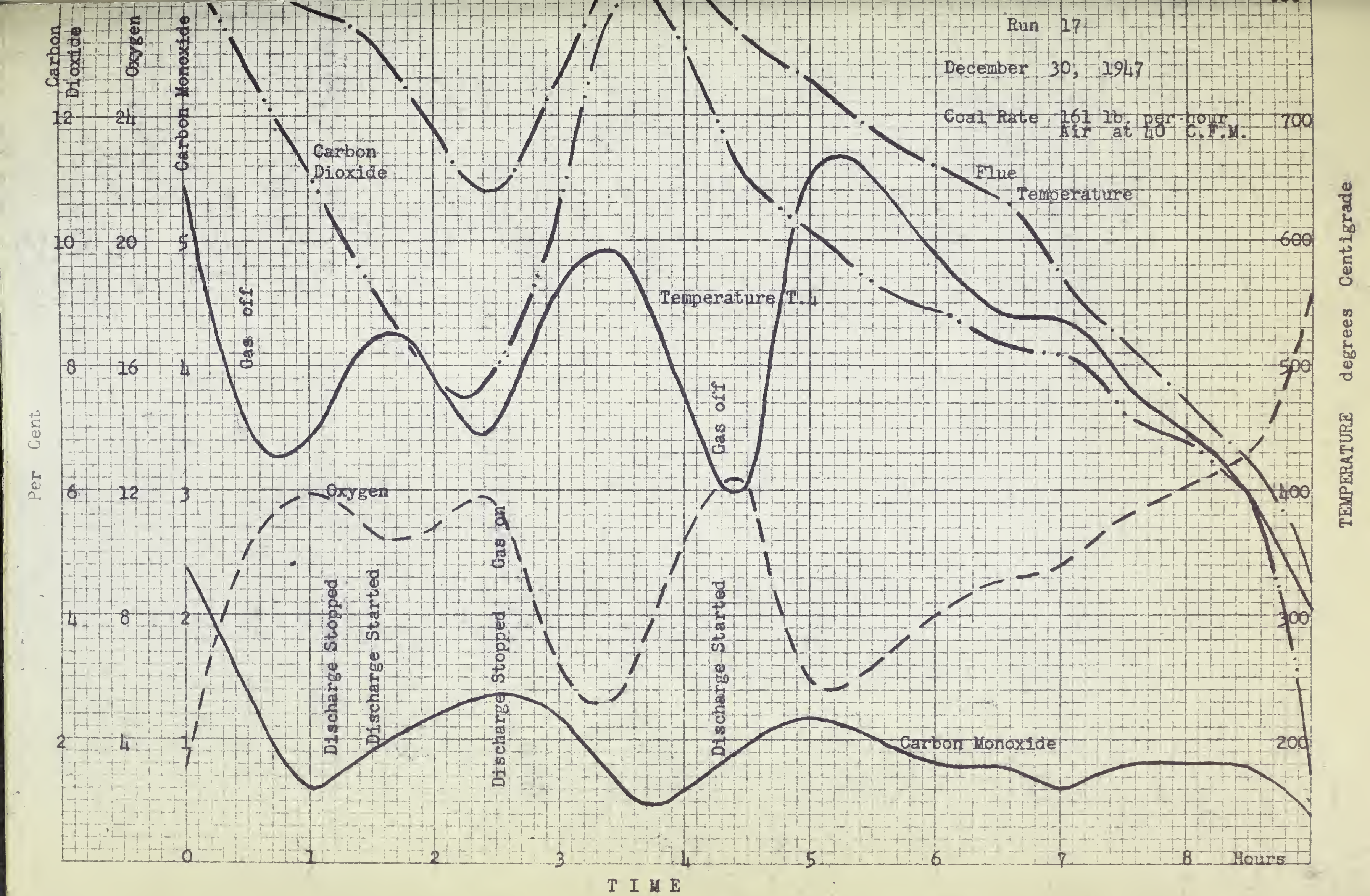
Yield of Char: 55 per cent.
Char Sample No. 623-47

Proximate Analysis of Char

	Per cent.
Ash	20.2
Volatile Matter	13.0
Fixed Carbon	66.8
	100.0

Air - coal ratio: 14.9 cu. ft. per lb. coal.

FIGURE XXXI



Run 17
December 30, 1947
Coal Rate 161 lb. per hour
Air at 40 C.F.M.
Carbon Dioxide
Oxygen
Carbon Monoxide
Per Cent
Carbon Dioxide
Flue Temperature
Temperature T.4
Gas off
Gas off
Oxygen
Gas on
Discharge Stopped
Discharge Started
Discharge Stopped
Discharge Started
Carbon Monoxide
TEMPERATURE degrees Centigrade
TIME
Hours

FIGURE XXXII

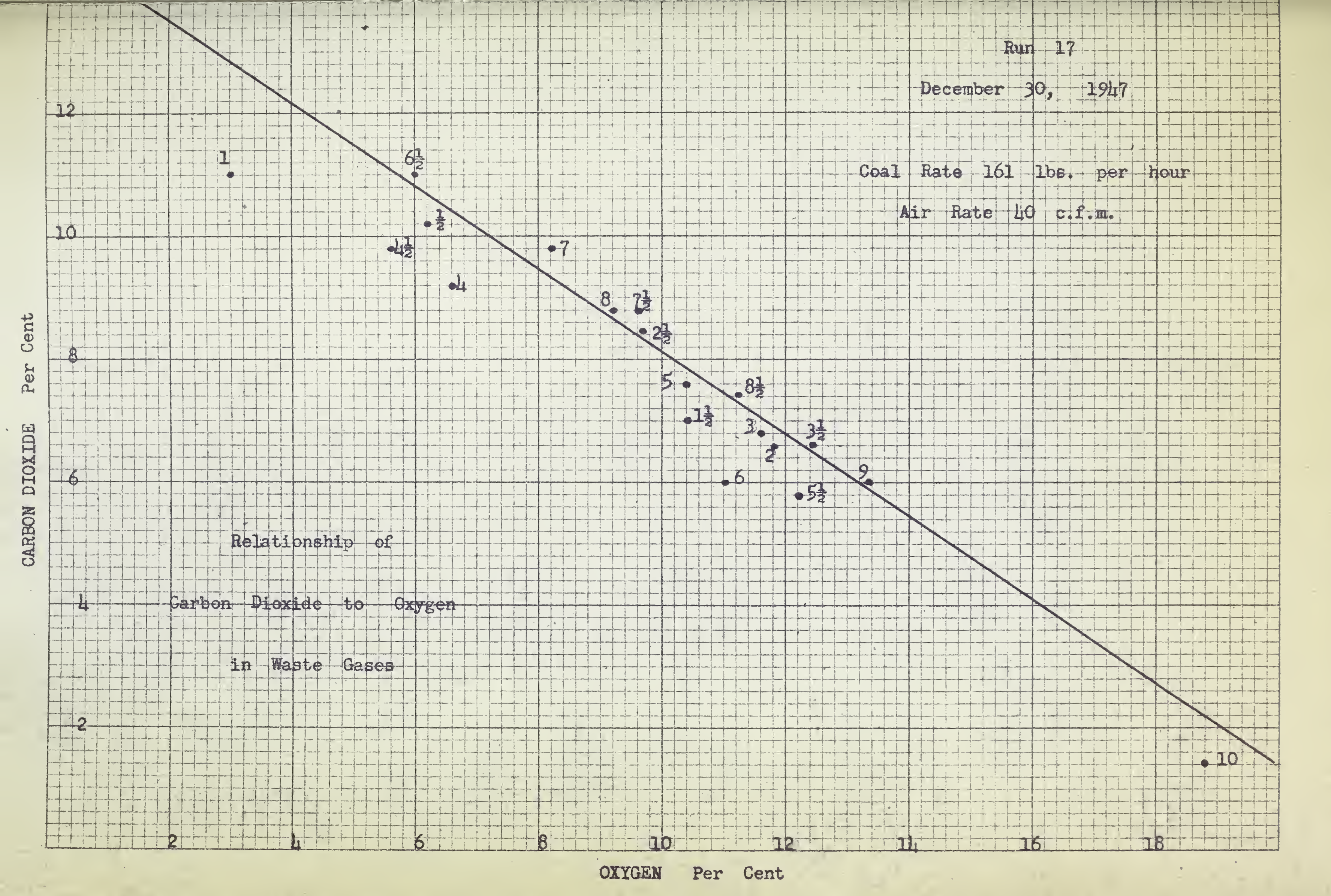
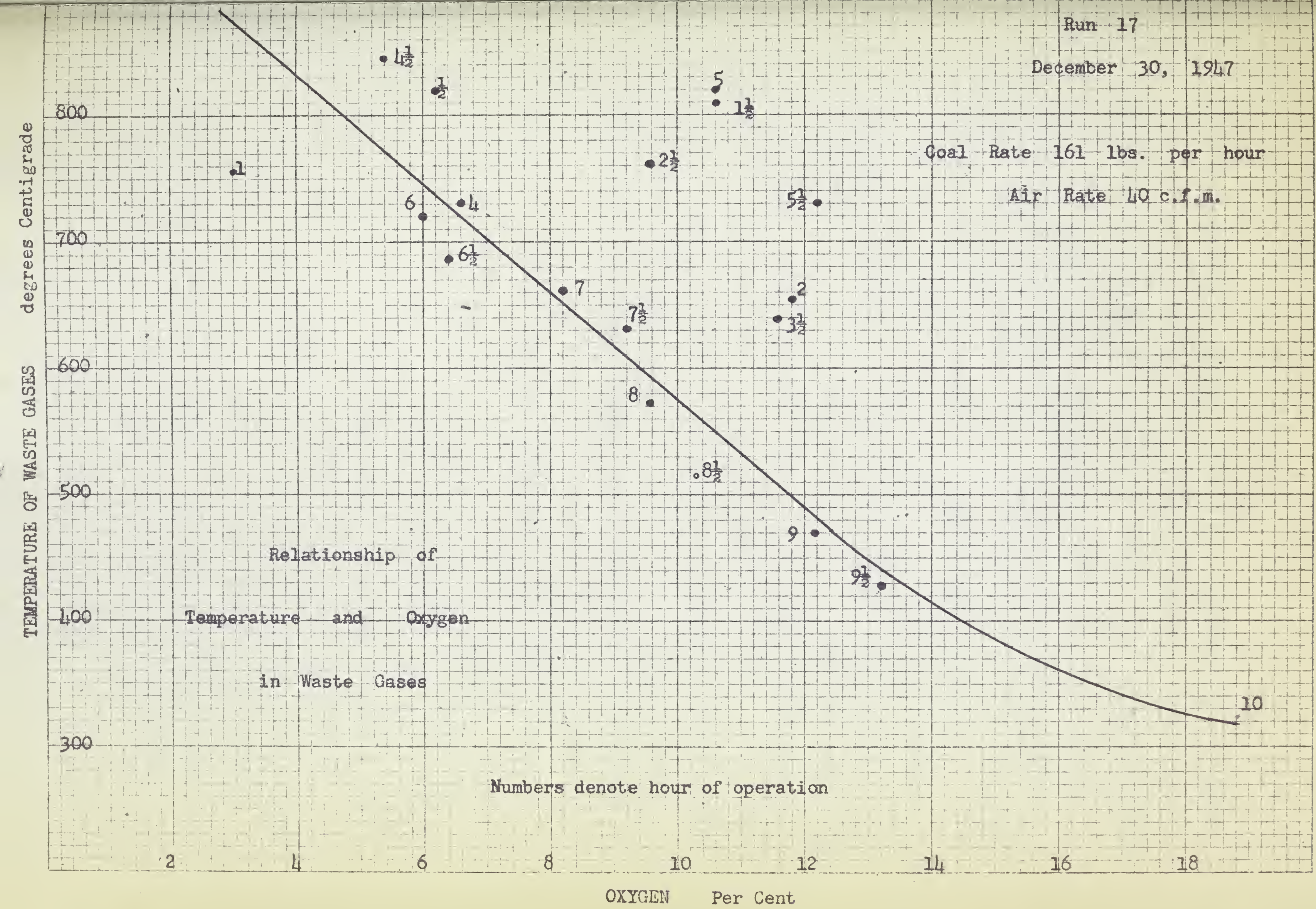

Run 17
December 30, 1947
Coal Rate 161 lbs. per hour
Air Rate 40 c.f.m.
Relationship of
Carbon Dioxide to Oxygen
in Waste Gases
CARBON DIOXIDE Per Cent
OXYGEN Per Cent
2
4
6
8
10
12
14
16
18
1
$6\frac{1}{2}$
$\frac{1}{2}$
$4\frac{1}{2}$
4
7
8
$7\frac{1}{2}$
$2\frac{1}{2}$
5
$8\frac{1}{2}$
$1\frac{1}{2}$
3
2
$3\frac{1}{2}$
6
$5\frac{1}{2}$
9
10

FIGURE XXXIII


Run 17
December 30, 1947
Coal Rate 161 lbs. per hour
Air Rate 40 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
Numbers denote hour of operation
TEMPERATURE OF WASTE GASES degrees Centigrade
OXYGEN Per Cent
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18

commensurate with complete combustion of the fuel. When combustion is incomplete this is indicated by the presence of carbon monoxide in combustion gases. The carbon monoxide may be accompanied by appreciable quantities of hydrogen and possibly hydrocarbons. The quantities of the latter gases are not usually determined because the determination involves explosion as well as absorption analysis.

In this experimental run, apart from the carbon monoxide in the flue gases, combustion of the distilled gases apparently was complete, save when operating conditions were abnormal, that is at times represented by points falling below the curve in Figure XXXII. Even when oxygen which, of course, represents excess air falls to as low as six per cent., the combustion was fairly complete apart from the gases represented by the carbon monoxide.

The amount of oxygen in the flue gases, that is to say the amount of excess air, can be related to the waste gas temperature as in Figure XXXIII. Again it will be seen that a fairly large number of points are above the straight portion of the curve in the graph and that these points represent periods in the run which fall below the line in Figure XXXII, that is to say periods when abnormal conditions of operations applied such as when the retort was being heated with natural gas or shortly after such a heating period. With regard to the point representing one hour after commencement of operation,

since in this case there was a large production of carbon monoxide, this naturally is represented on a position falling below the curve.

(b) Run number 18 was a repetition of run number 17 except that the period between charging the retort with coal and the commencement of operation of the discharge mechanism was varied. It was recognized that if reasonably high flue gas and carbonization temperatures were to be attained, the coal undergoing carbonization in the initial periods must not lose too large a quantity of volatile matter before the discharge was started and an approach made to steady conditions of carbonization. Accordingly, during the first part of the run when the flue temperatures had fallen rapidly, in an effort to regain high temperatures in the retort, the discharge was turned off and the retort heated with natural gas. The discharge was started before the flue gas temperature had passed its peak and the flue gas temperature commenced to fall again due to the excessive loss of the volatile matter from the stationary coal in the retort. Unfortunately, the oxygen of the waste gases under these conditions fell to a very low figure so that it seemed possible that combustion of the whole of the volatile matter distilled from the coal might be far from complete. Thereafter, the retort was run with a constant air supply and discharge rate until the temperatures fell so low that the flames in the flues expired. The results are shown in Table XXXIII and Figure XXXIV.

[illegible]

[illegible]

TABLE XXXIII

Trial Run No. 18 — January 2, 1948.
Coal throughput 161 lbs. per hour. — Air rate 40 c.f.m.

T.C. Number	Time after charging, Hours					
	1/2	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3
	Temperature °C.					
1	416	372	336	334	310	294
2	314	428	431	368	355	307
4	598	708	725	626	576	520
5	105	364	602	570	544	518
6	32	71	574	553	520	516
7	770	770	780	750	660	420
8	770	795	780	750	710	710
	Percentage in Flue Gases					
Carbon Dioxide	11.0	9.7	12.4	10.0	9.0	6.0
Oxygen	4.0	3.5	2.4	6.4	8.2	10.6
Carbon Monoxide	1.2	1.6	1.4	1.6	1.6	3.2

T.C. Number	Time after charging, Hours				
	$3\frac{1}{2}$	4	$4\frac{1}{2}$	5	$5\frac{1}{2}$
	Temperature °C				
1	296	473	525	341	314
2	302	511	595	398	336
4	488	580	761	682	656
5	459	464	666	640	630
6	440	392	436	609	593
7	295	420	635	700	680
8	700	795	820	720	680
	Percentage in Flue Gases				
Carbon Dioxide	4.2	6.0	12.6	10.0	10.4
Oxygen	10.3	8.2	1.4	7.0	6.6
Carbon Monoxide	5.2	3.4	2.0	1.2	2.2

T.C. Number	Time after charging, Hours 6	6½	7	7½	8
	Temperature °C.				
1	278	292	305	290	314
2	298	314	312	320	369
4	607	612	593	544	486
5	602	605	607	562	471
6	534	546	513	480	400
7	615	495	280	280	250
8	655	690	710	710	650

Percentage in Flue Gases

Carbon Dioxide	10.0	9.0	6.4	4.8	4.0
Oxygen	7.0	8.4	10.4	13.0	15.8
Carbon Monoxide	1.6	1.6	1.8	2.2	2.6

Remarks:

Flames in North flue expired after seven hours of operation.

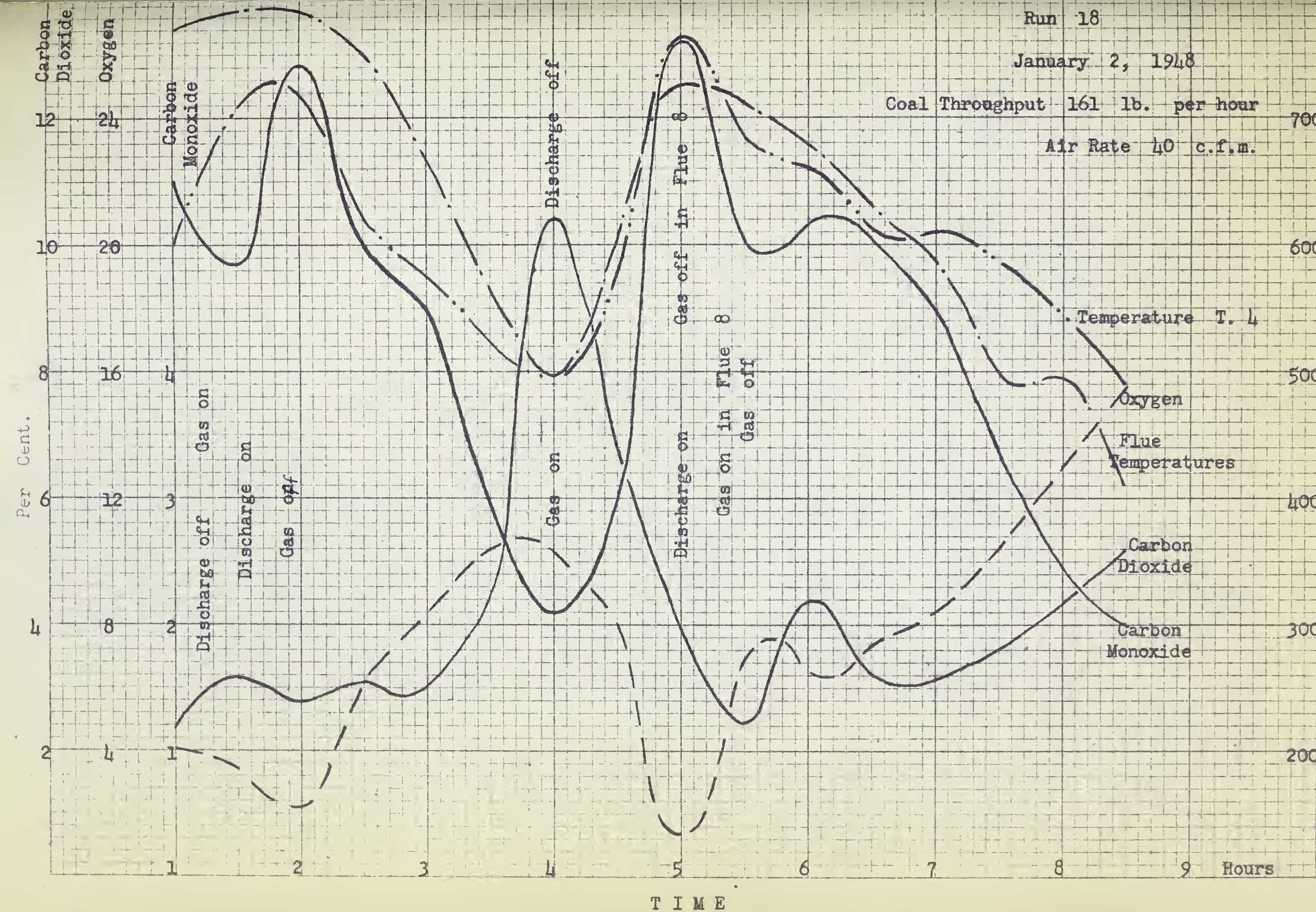
Yield of Char: 55 per cent.
Char sample No. 601-48
Air - coal ratio: 14.9 cu. ft. air per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	20.8
Volatile Matter	12.4
Fixed Carbon	66.6
	100.0

Calorific Value, B.t.u. per lb. 11,330

FIGURE XXXIV



Run 18
January 2, 1948
Coal Throughput 161 lb. per hour
Air Rate 40 c.f.m.
Carbon Dioxide
Oxygen
Carbon Monoxide
Per Cent.
TEMPERATURE degrees Centigrade
Discharge off
Gas on
Discharge on
Gas off
Discharge off
Gas on
Gas off in Flue 8
Discharge on
Gas on in Flue 8
Gas off
Temperature T. 4
Oxygen
Flue Temperatures
Carbon Dioxide
Carbon Monoxide
Hours
TIME

No explanation can be given of the high carbon monoxide content in the waste gases between third and fifth hours of operation. This may be due to low temperatures in the retort flues or may represent unusual conditions of coal distillation.

The relation of carbon dioxide and flue gas temperature to the oxygen contents of the flue gases are shown in Figures XXXV and XXXVI, respectively. Comparing Figure XXXV with Figure XXXII it will be seen that the curve on Figure XXV falls appreciably below the one in Figure XXXII, the distance between the curves increasing as the quantity of excess air increases. The curve on Figure XXXV has been drawn as reasonably representative of the points on the graph and the scattering is no doubt due to the presence of unburned gas. The origins of the curves on Figures XXXII and XXXV must obviously be the same for theoretical air conditions, that is to say at 15 per cent. carbon dioxide.

With regards to Figure XXXVI, as far as the points falling below six per cent. oxygen are concerned, that representative of $4\frac{1}{2}$ hours can be ascribed to low temperatures and the high carbon monoxide content of the waste gases; with respect to the positions at 1/2, 1 and 1 1/2 hours, at these times, although the volume of gas from the freshly charged retort was high, due to the high temperatures in the flues through the heating with natural gas, combustion conditions were good and in spite of the high volume of gas, the carbon monoxide content was low.

FIGURE XXXV

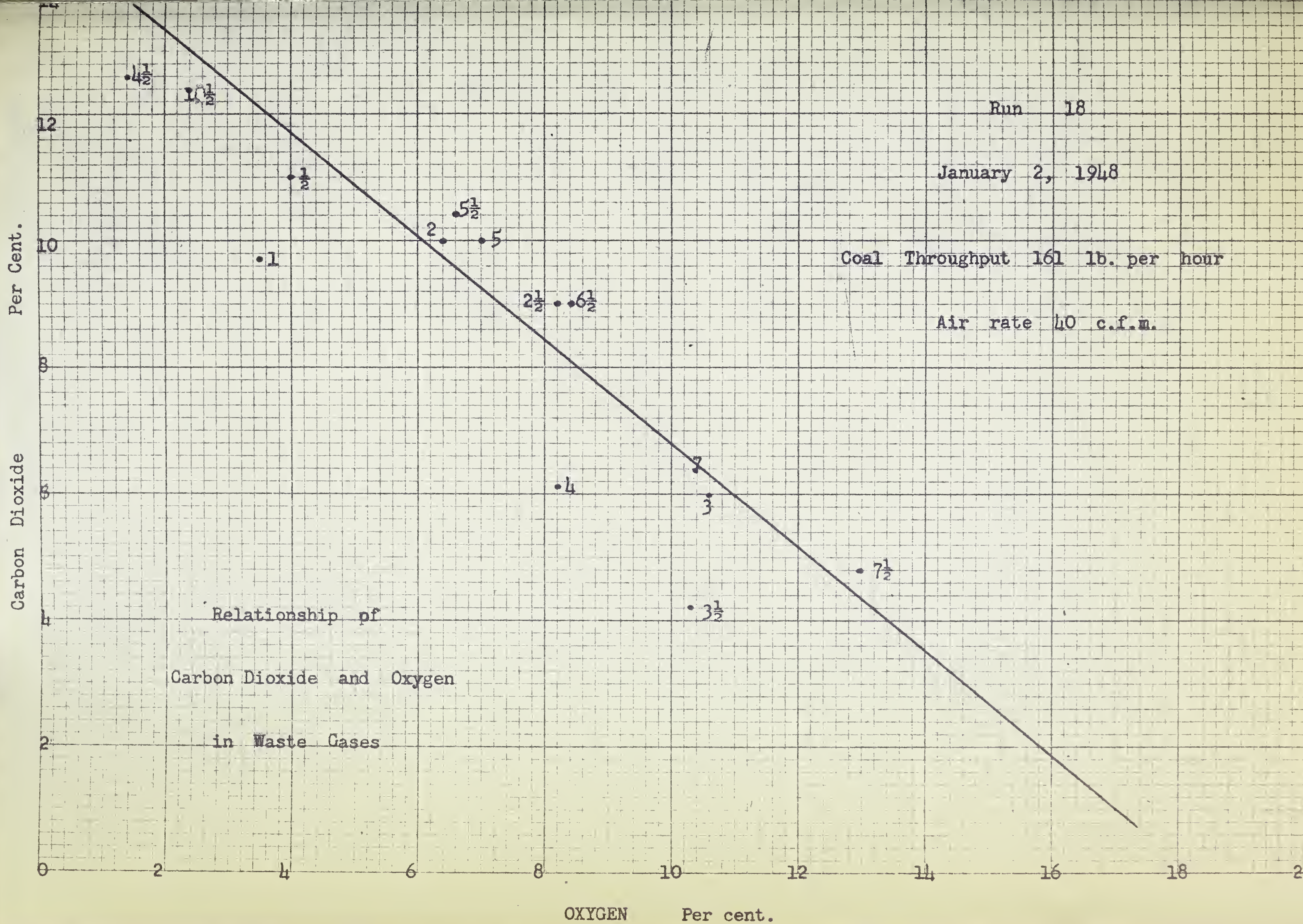
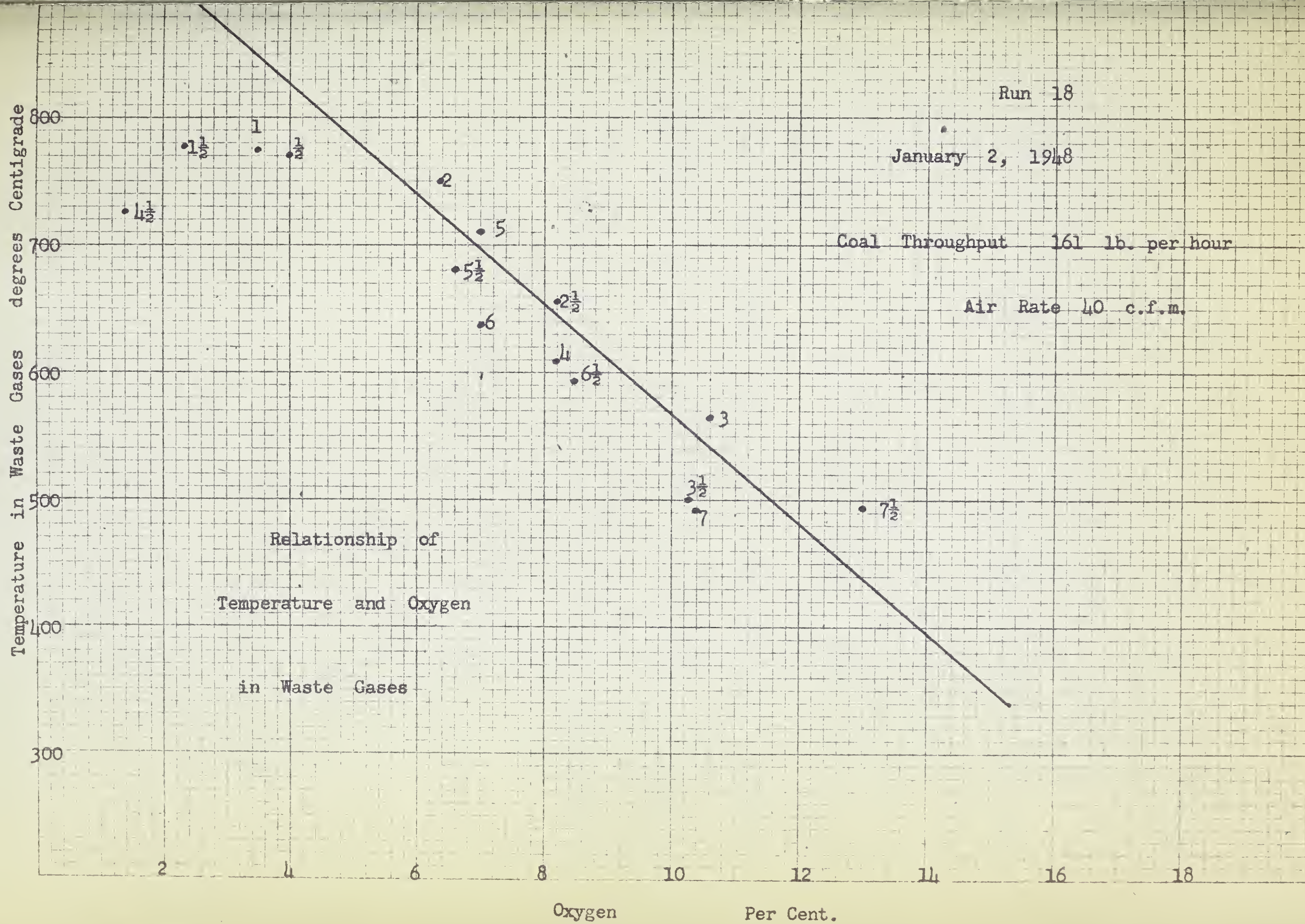

Run 18
January 2, 1948
Coal Throughput 161 lb. per hour
Air rate 40 c.f.m.
Relationship of
Carbon Dioxide and Oxygen
in Waste Gases
Carbon Dioxide Per Cent.
OXYGEN Per cent.
0
2
4
6
8
10
12
14
16
18
20
$4\frac{1}{2}$
$10\frac{1}{2}$
$\frac{1}{2}$
$5\frac{1}{2}$
2
5
1
$2\frac{1}{2}$
$6\frac{1}{2}$
4
7
3
$7\frac{1}{2}$
$3\frac{1}{2}$

FIGURE XXXVI



Run 18
January 2, 1948
Coal Throughput 161 lb. per hour
Air Rate 40 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
Temperature in Waste Gases degrees Centigrade
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18
Oxygen Per Cent.
1
1½
½
4½
2
5
5½
2½
6
4
6½
3
3½
7
7½

(c) In order to confirm the conslusions arrived at from the results of the two preceding runs, four further trial runs were made with variations on throughput and air supply. The results obtained are shown in Tables XXXIV to XXXVII and Figures XXXVII, XL, XLIII and XLVI.

Figures XXXVIII, XLI, XLIV and XLVII show that in all four experimental runs, combustion of the volatile matter was substantially complete but over the entire periods of runs there were progressive increases in the oxygen content and hence the quantity of excess air in the flue gases. Figures XXXIX, XLII, XLV and XLVIII show that at the initial stages of the runs there was a considerable shortage of excess air, but that after a period of two hours excess air conditions gave straight line relationships with the flue gas temperatures. It will be noted also that, as the rate of air supply per pound of coal increased, the curves tended to move to the right, that is representing an increase in the quantity of excess air.

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]

[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
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[illegible]
[illegible]
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TABLE XXXIV

Trial Run No. 19 — January 6, 1948.
Coal throughput 160 lbs. per hour — Air rate 60 c.f.m.

	Time after charging, Hours				
	½	1	1½	2	2½
T.C. Number	Temperature °C.				
4	708	752	764	612	560
5	248	450	623	565	548
6	30	54	558	565	560
7	850	850	850	800	745
8	934	934	860	780	700
	Per cent. in Flue Gases				
Carbon Dioxide	11.0	14.2	9.6	7.6	6.9
Oxygen	5.0	0.8	7.4	10.3	12.3
Carbon Monoxide	0.8	0.8	0.6	0.5	0.6

	Time after charging, Hours				
	3	3½	4	4½	5
T.C. Number	Temperature oC.				
4	640	722	807	754	612
5	501	511	728	725	628
6	392	368	640	708	602
7	770	825	800	790	715
8	850	908	900	830	715
	Per cent. in Flue Gases				
Carbon Dioxide	7.4	8.4	10.0	9.2	8.2
Oxygen	9.8	7.8	5.4	8.8	10.8
Carbon Monoxide	0.6	0.6	0.4	0.4	0.4

T.C. Number	Time after charging, Hours 5½	6	6½	7	7½
	Temperature °C.				
4	537	468	480	471	392
5	600	532	536	504	416
6	508	492	464	443	365
7	660	560	380	265	230
8	590	490	510	510	360
	Per cent. in flue Gases				
Carbon Dioxide	6.4	5.6	4.0	3.0	1.0
Oxygen	12.8	14.0	16.2	16.8	19.6
Carbon Monoxide	0.5	0.4	0.2	0.2	0.2

Remarks:

Thermocouples 1 and 2 burned out.
Thermocouple No. 2 guard fused.

Yield of char 56.2 per cent.
Char sample No. 602-48
Air - coal ratio: 22.5 cu. ft. per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	23.3
Volatile Matter	12.0
Fixed Carbon	64.7
	100.0

Calorific Value, B.t.u. per lb. 10,910

[illegible]

TABLE XXXV

Trial Run No. 20 — January 8, 1948.
Coal throughput 65 lbs. per hour — Air rate 25 c.f.m.

	Time after charging, Hours						
	½	1	1½	2	2½	3	3½
T.C. Number	Temperature °C.						
1	486	630	522	560	523	536	466
4	682	628	609	539	504	471	452
5	179	249	369	376	374	369	379
6	50	54	64	355	370	374	392
7	845	850	876	830	800	790	750
8	892	850	845	830	790	775	740
	Per cent. in Flue Gases						
Carbon Dioxide	8.6	10.4	8.2	6.2	7.6	6.6	6.6
Oxygen	9.0	7.4	9.8	12.6	11.4	12.6	12.4
Carbon Monoxide	0.4	0.2	0.4	0.4	0.4	0.2	0.4

	Time after charging, Hours					
	4	4½	5	5½	6	6½
T.C. Number	Temperature °C.					
1	424	398	358	341	288	251
4	438	426	410	398	386	374
5	384	392	388	388	385	388
6	396	400	405	400	400	396
7	730	720	710	655	635	655
8	690	655	710	560	525	475
	Per cent. in Flue Gases					
Carbon Dioxide	5.8	7.2	6.6	6.8	6.4	6.0
Oxygen	13.6	12.0	12.4	12.4	12.8	13.5
Carbon Monoxide	0.5	0.3	0.4	0.4	0.4	0.2

	Time after charging, Hours					
	7	7½	8	8½	9	9½
T.C. Number	Temperature °C					
1	214	194	177	160	162	154
4	368	374	369	376	386	376
5	379	392	405	410	426	426
6	392	392	391	393	398	405
7	640	700	710	690	670	650
8	380	315	290	270	240	235
	Percent. in Flue Gases					
Carbon Dioxide	5.6	5.8	5.8	6.2	5.6	5.2
Oxygen	14.0	13.4	13.5	13.3	13.9	14.3
Carbon Monoxide	0.3	0.5	0.5	0.3	0.3	0.3

Remarks:

Flames in South flue expired after 7 1/2 hours of operation.

Yield of char: 57.3 per cent.
Char sample No. 603-48

Air - coal ratio: 23.1 cu. ft. per lb. coal

Proximate Analysis of Char

	Per cent.
Ash	29.1
Volatile Matter	6.5
Fixed Carbon	64.4
	100.0

Calorific Value, B.t.u. per lb. 10,240

TABLE XXXVI

Trial Run No. 21 — January 13, 1948.
Throughput 92 lbs. per hour — Air Rate 30 c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½	3
	Temperature °C.					
1	408	412	441	412	416	264
4	678	682	643	570	556	522
5	204	440	438	471	471	478
6	60	74	412	468	483	499
7	850	850	840	830	825	770
8	850	850	840	790	780	710

Percentage in Flue Gases

	½	1	1½	2	2½	3
Carbon Dioxide	12.0	12.4	10.9	8.8	10.6	8.6
Oxygen	5.0	3.8	5.7	9.4	7.0	9.2
Carbon Monoxide	0.8	0.4	0.3	0.2	0.6	0.6

Time after Charging, Hours

T.C. Number	3½	4	4½	5	5½
	Temperature °C.				
1	280	288	272	278	239
4	494	471	455	438	426
5	459	438	436	419	405
6	478	445	452	428	422
7	765	815	720	710	710
8	710	685	665	620	600

Percentage in Flue Gases

	3½	4	4½	5	5½
Carbon Dioxide	9.8	9.2	8.6	8.1	8.4
Oxygen	8.1	8.4	10.6	10.5	10.2
Carbon Monoxide	0.5	0.4	0.5	0.6	0.2

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[illegible]

[illegible]

T.C. Number	Time after Charging, Hours: 6	6½	7	7½	8
	Temperature °C.				
1	222	217	194	194	148
4	422	405	392	386	344
5	393	392	392	396	358
6	416	414	424	438	398
7	640	575	530	475	415
8	560	525	460	365	335
	Per cent. in Flue Gases				
Carbon Dioxide	7.6	5.8	5.6	4.0	3.2
Oxygen	12.2	13.8	14.3	16.0	17.6
Carbon Monoxide	0.4	0.4	0.4	0.6	0.6

Remarks:

Flames in South flue expired 7½ hours after charging the retort.

Yield of Char: 53 per cent.
Char Sample No. 604-48

Air - coal Ratio: 19.6 cu. ft. per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	21.5
Volatile Matter	7.0
Fixed Carbon	71.5
	100.0

Calorific Value, B.t.u. per lb. 10,360

TABLE XXXVII

Trial Run No. 22 — January 15, 1948.
Coal throughput 68 lbs. per hour — Air rate 15 c.f.m.

	Time after charging, Hours						
	½	1	1½	2	2½	3	3½
T.C. Number	Temperature °C.						
1	222	374	572	590	560	490	497
4	661	734	798	635	584	542	504
5	296	344	369	454	457	429	412
6	50	52	54	64	159	393	381
7	650	680	820	795	765	730	750
8	720	710	840	795	765	730	715
	Per cent. in Flue Gases						
Carbon Dioxide	12.2	8.3	5.8	6.0	7.2	6.2	
Oxygen	2.6	9.7	13.4	13.3	11.6	12.4	
Carbon Monoxide	1.2	0.4	0.3	0.3	0.4	0.6	

	Time after charging, Hours						
	4	4½	5	5½	6	6½	7
T.C. Number	Temperature °C.						
1	497	492	486	483	492	504	478
4	635	757	687	626	581	560	536
5	476	572	572	532	488	478	462
6	392	422	499	513	488	486	464
7	750	755	780	795	810	810	795
8	780	795	825	795	810	795	790
	Per cent. in Flue Gases						
Carbon Dioxide	10.3	11.0	12.1	10.6	8.6	12.0	11.2
Oxygen	4.3	3.6	4.3	6.2	8.0	4.4	4.4
Carbon Monoxide	1.0	1.7	1.1	1.0	1.0	1.0	1.0

Time after Charging, Hours

T.C. Number	7½	8	8½	9	9½	10	10½
	Temperature °C.						
1	452	431		376	360	350	312
4	520	511		497	488	478	471
5	454	443		436	431	431	412
6	462	452		455	450	455	452
7	780	790		780	735	715	710
8	780	775		780	730	710	700
	Per cent. in Flue Gases						
Carbon Dioxide	11.2	10.8	11.8	11.5	11.4	10.2	11.0
Oxygen	5.0	5.4	4.1	5.1	5.6	7.2	6.3
Carbon Monoxide	1.0	1.2	1.0	0.8	0.9	0.6	0.5

	11	11½	12	12½	13	13½	14
1	346	348	310	324	292	273	256
4	457	450	438	438	438	433	426
5	410	402	393	392	396	388	393
6	446	438	436	443	448	448	457
7	710	690	680	635	620	560	550
8	690	690	680	695	690	660	630
Carbon Dioxide	10.2	10.2	10.4	9.2	9.1	8.0	7.8
Oxygen	7.2	7.6	7.4	8.7	8.6	10.0	10.4
Carbon Monoxide	0.6	0.6	0.8	0.7	0.6	0.8	0.8

Remarks:

Yield of Char: 55 per cent.
Char Sample No. 605-48
Air - coal Ratio: 13.8 cu. ft. per lb. coal

Proximate Analysis of Char

	Per cent.
Ash	21.8
Volatile Matter	10.8
Fixed Carbon	67.4
	100.0

Calorific Value, B.t.u. per lb. 11,340

FIGURE XXXVII

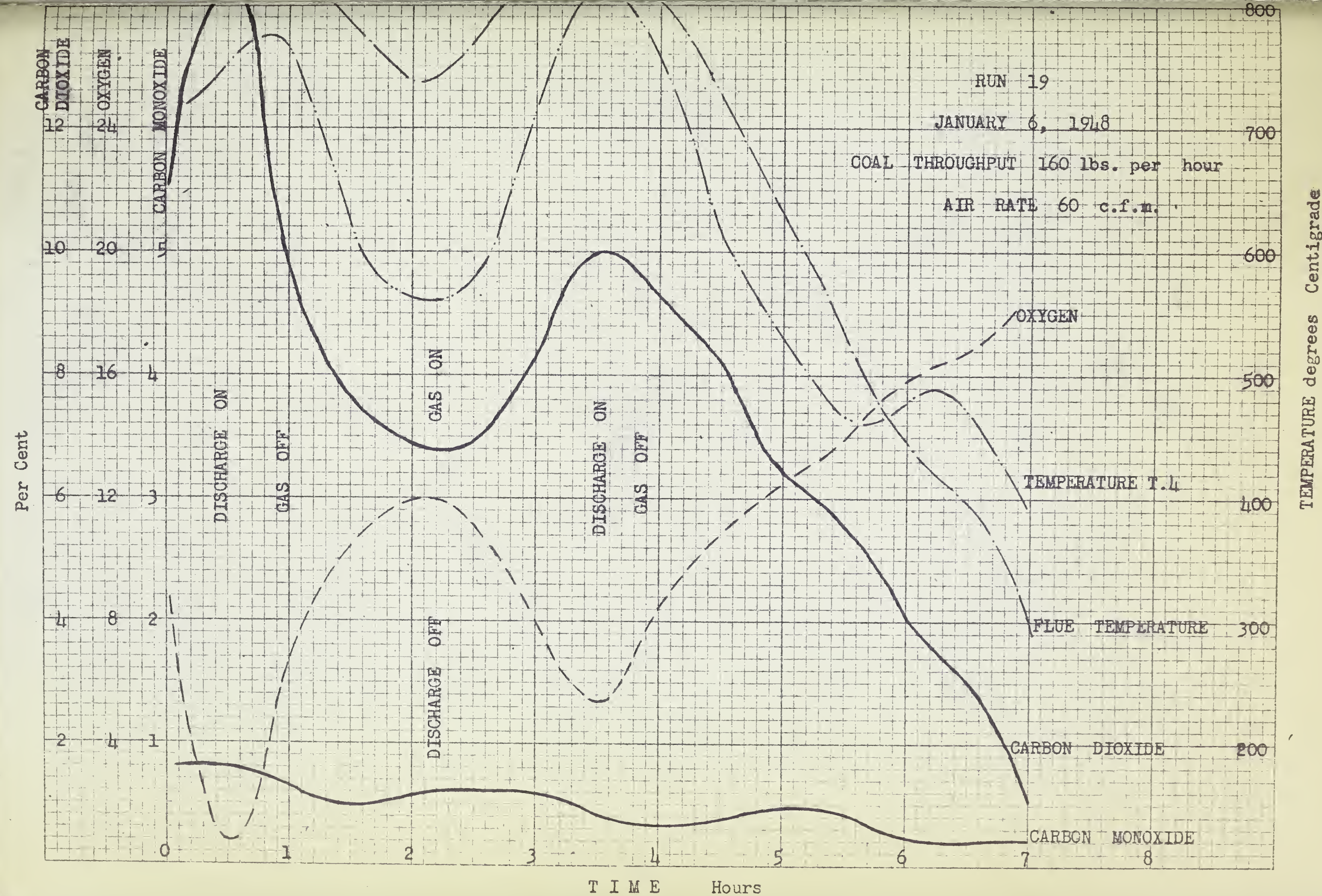

RUN 19
JANUARY 6, 1948
COAL THROUGHPUT 160 lbs. per hour
AIR RATE 60 c.f.m.
CARBON DIOXIDE
OXYGEN
CARBON MONOXIDE
Per Cent
TEMPERATURE degrees Centigrade
DISCHARGE ON
GAS OFF
GAS ON
DISCHARGE OFF
DISCHARGE ON
GAS OFF
OXYGEN
TEMPERATURE T.4
FLUE TEMPERATURE
CARBON DIOXIDE
CARBON MONOXIDE
TIME Hours

FIGURE XXXVIII

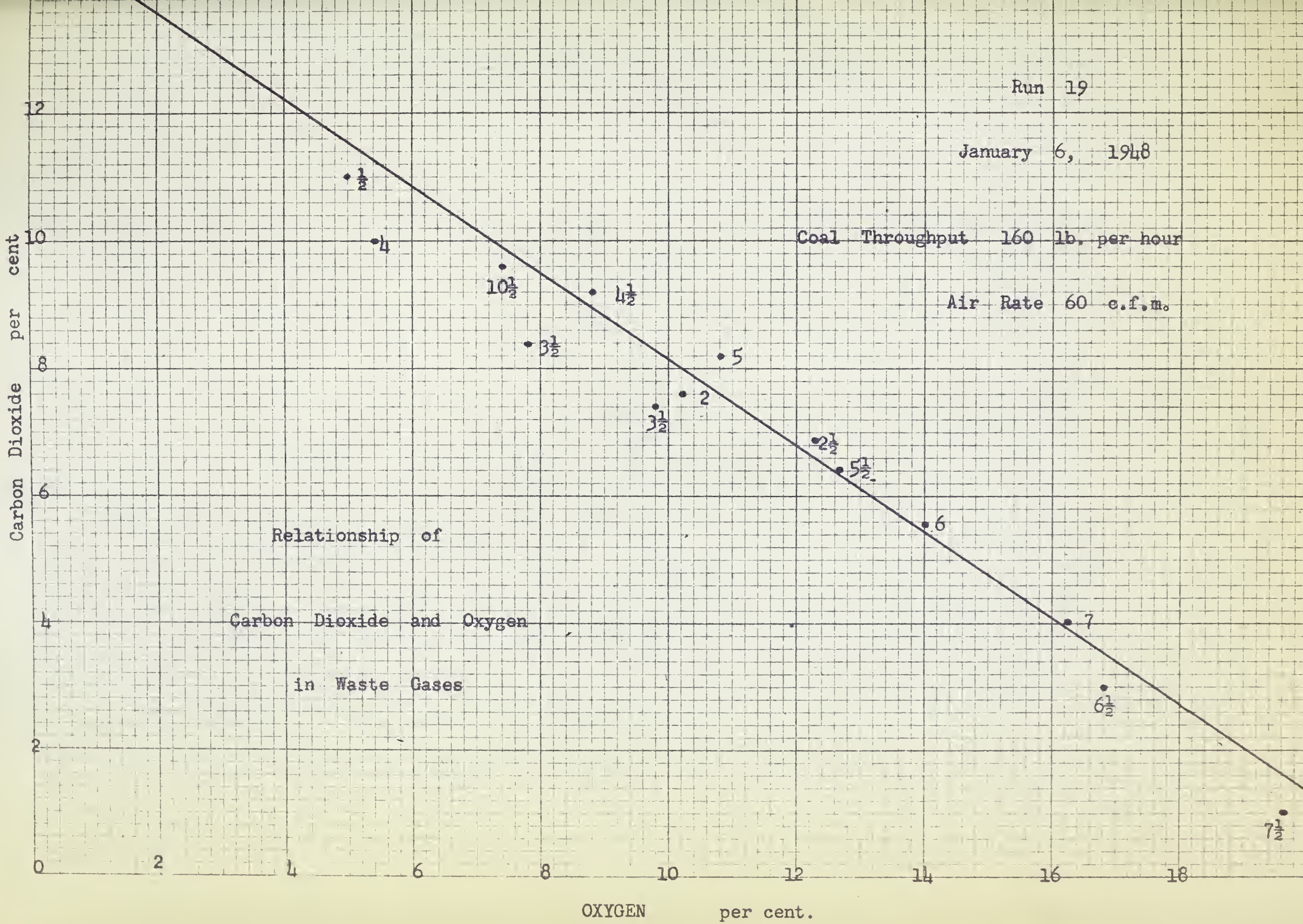

Run 19
January 6, 1948
Coal Throughput 160 lb. per hour
Air Rate 60 c.f.m.
Relationship of
Carbon Dioxide and Oxygen
in Waste Gases
Carbon Dioxide per cent
OXYGEN per cent.
0
2
4
6
8
10
12
14
16
18
½
4
10½
4½
3½
5
2
3½
2½
5½
6
7
6½
7½

FIGURE XXXIX

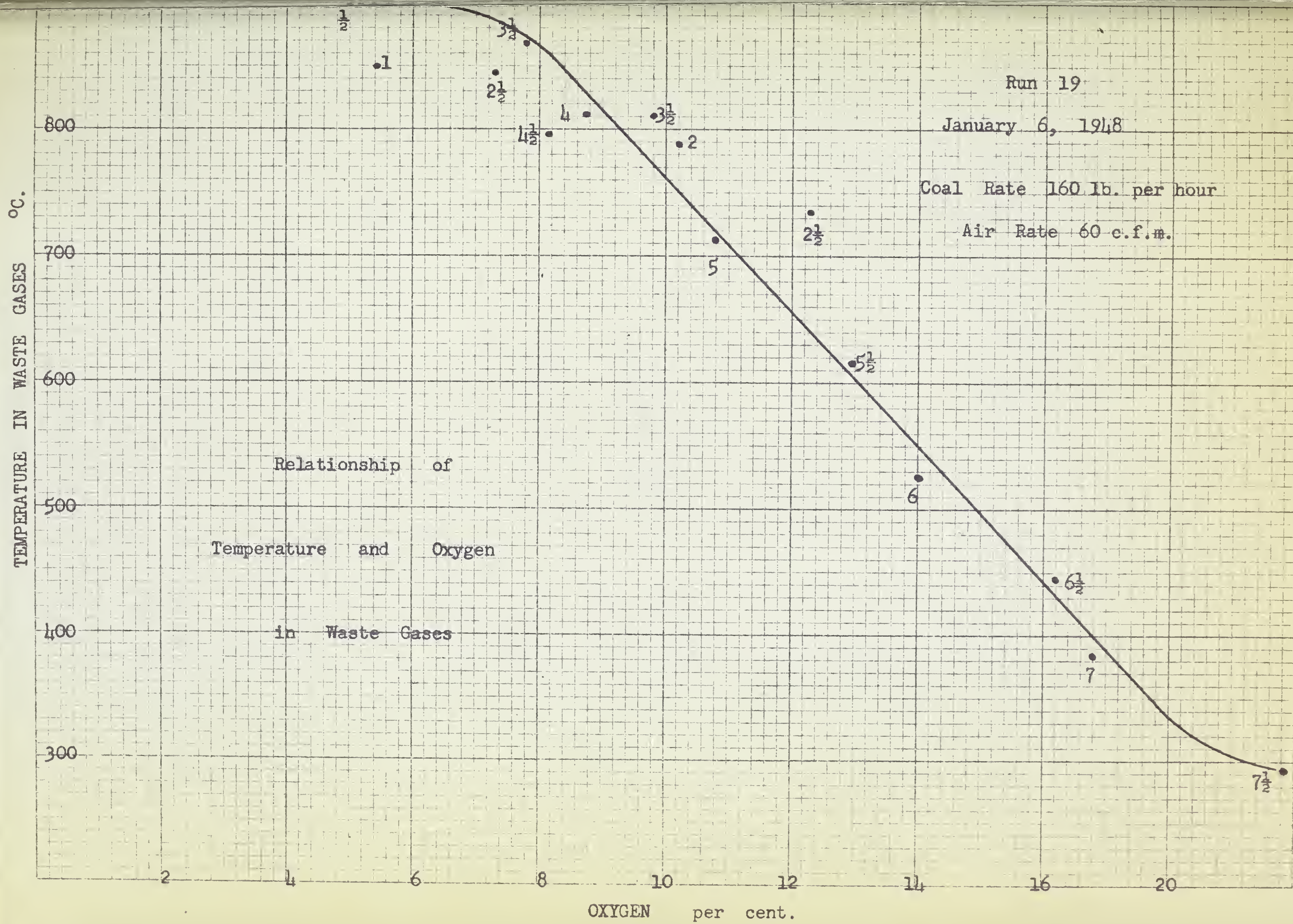
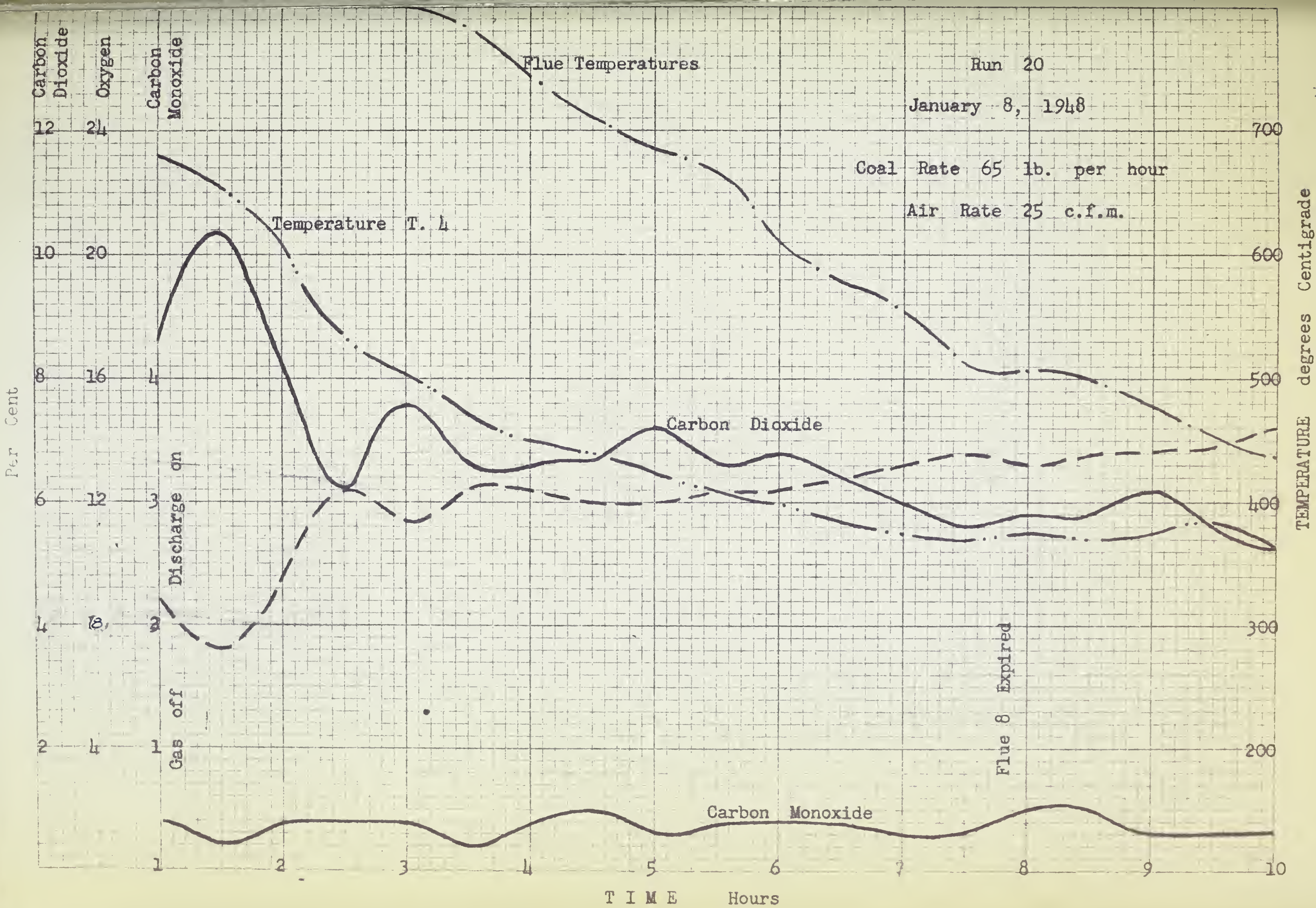
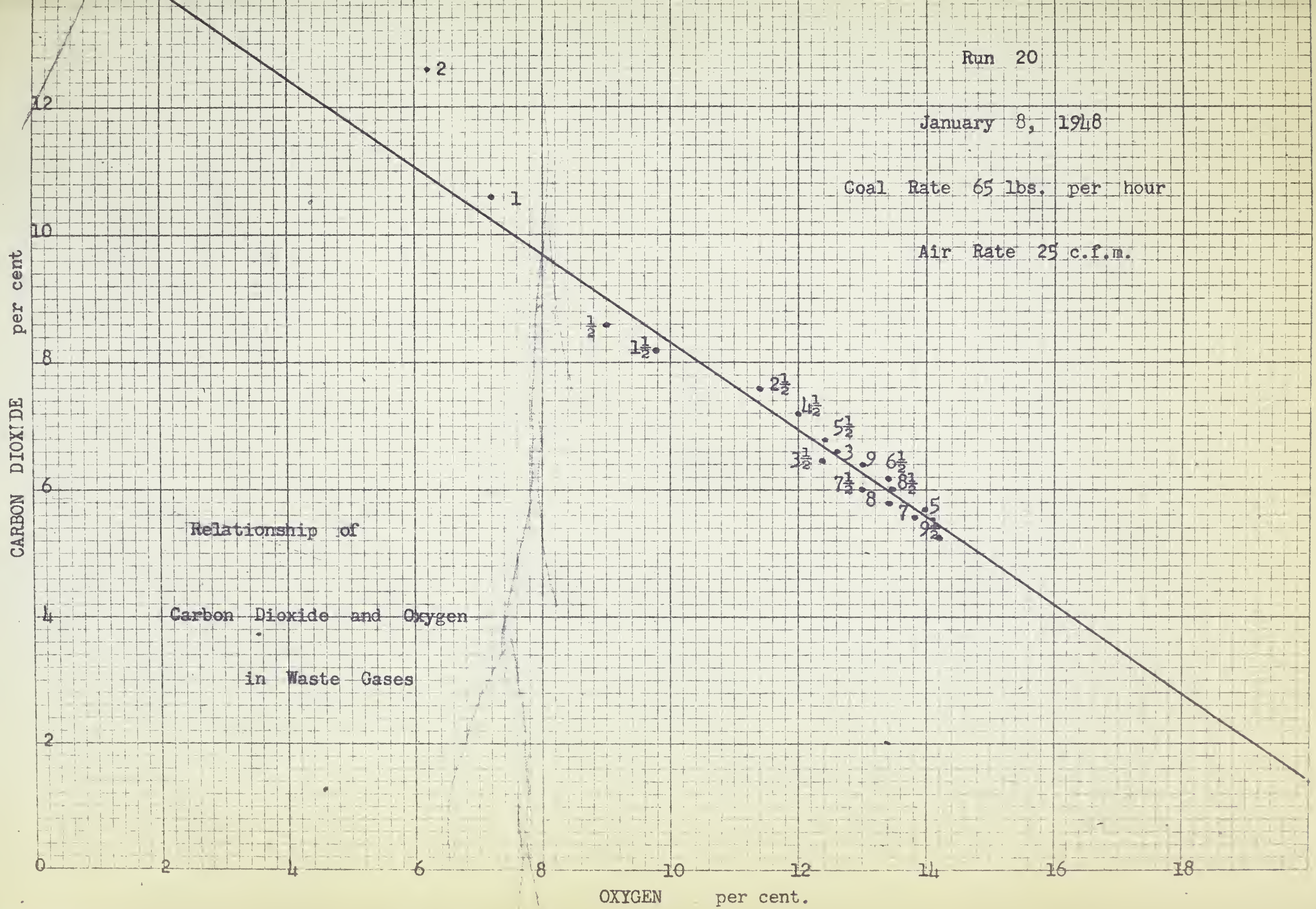

Run 19
January 6, 1948
Coal Rate 160 lb. per hour
Air Rate 60 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
TEMPERATURE IN WASTE GASES °C.
800
700
600
500
400
300
2
4
6
8
10
12
14
16
20
OXYGEN per cent.

FIGURE XL



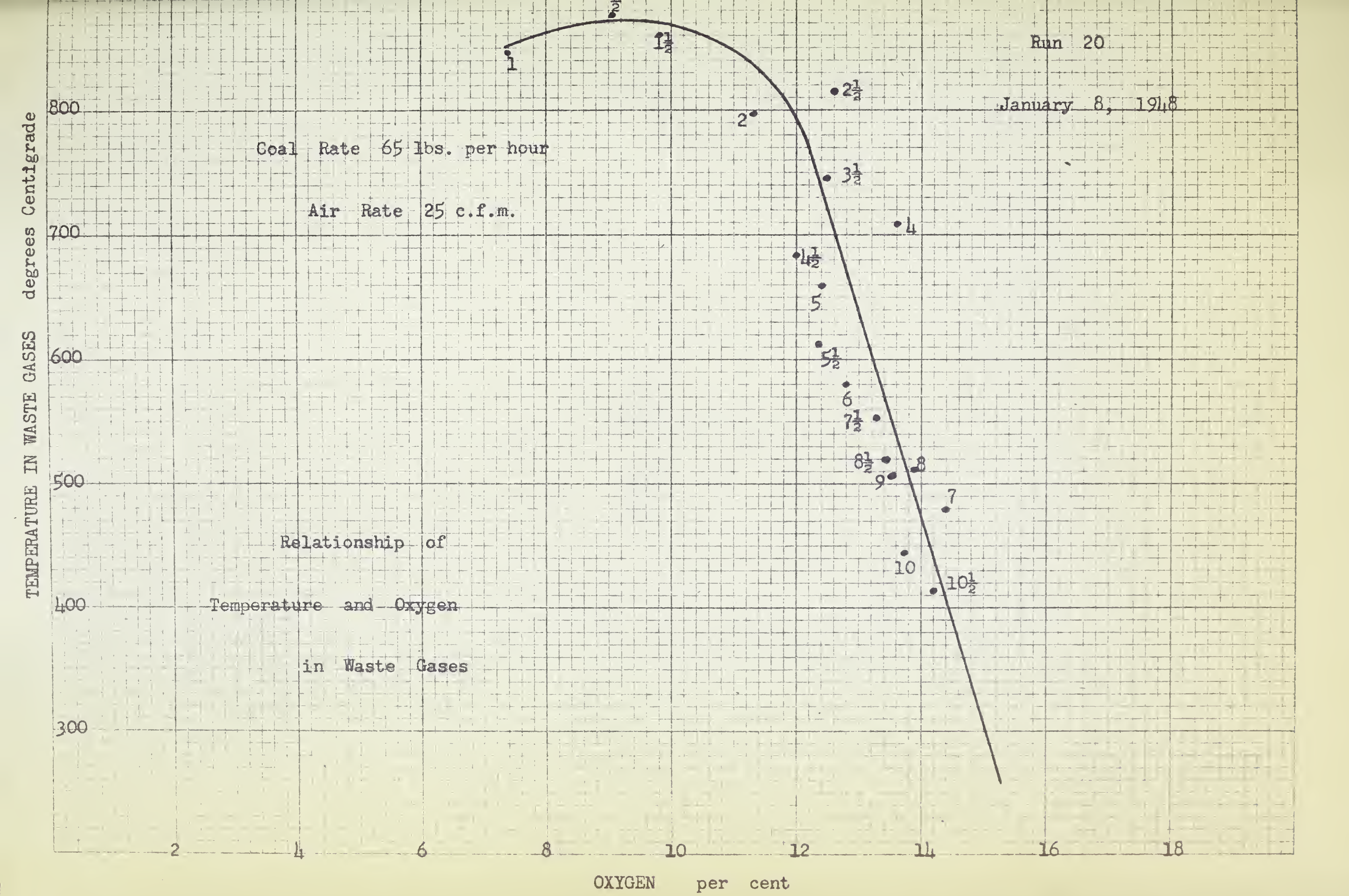
Carbon Dioxide
Oxygen
Carbon Monoxide
Flue Temperatures
Run 20
January 8, 1948
Coal Rate 65 lb. per hour
Air Rate 25 c.f.m.
Temperature T. 4
Carbon Dioxide
Discharge on
Gas off
Flue 8 Expired
Carbon Monoxide
TEMPERATURE degrees Centigrade
Per Cent
TIME Hours

FIGURE XLI



Run 20
January 8, 1948
Coal Rate 65 lbs. per hour
Air Rate 25 c.f.m.
Relationship of
Carbon Dioxide and Oxygen
in Waste Gases
CARBON DIOXIDE per cent
OXYGEN per cent.

FIGURE XLII



Run 20
January 8, 1948
Coal Rate 65 lbs. per hour
Air Rate 25 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
TEMPERATURE IN WASTE GASES degrees Centigrade
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18
OXYGEN per cent
1
1½
2
2½
3½
4
4½
5
5½
6
7
7½
8
8½
9
10
10½

FIGURE XLIII

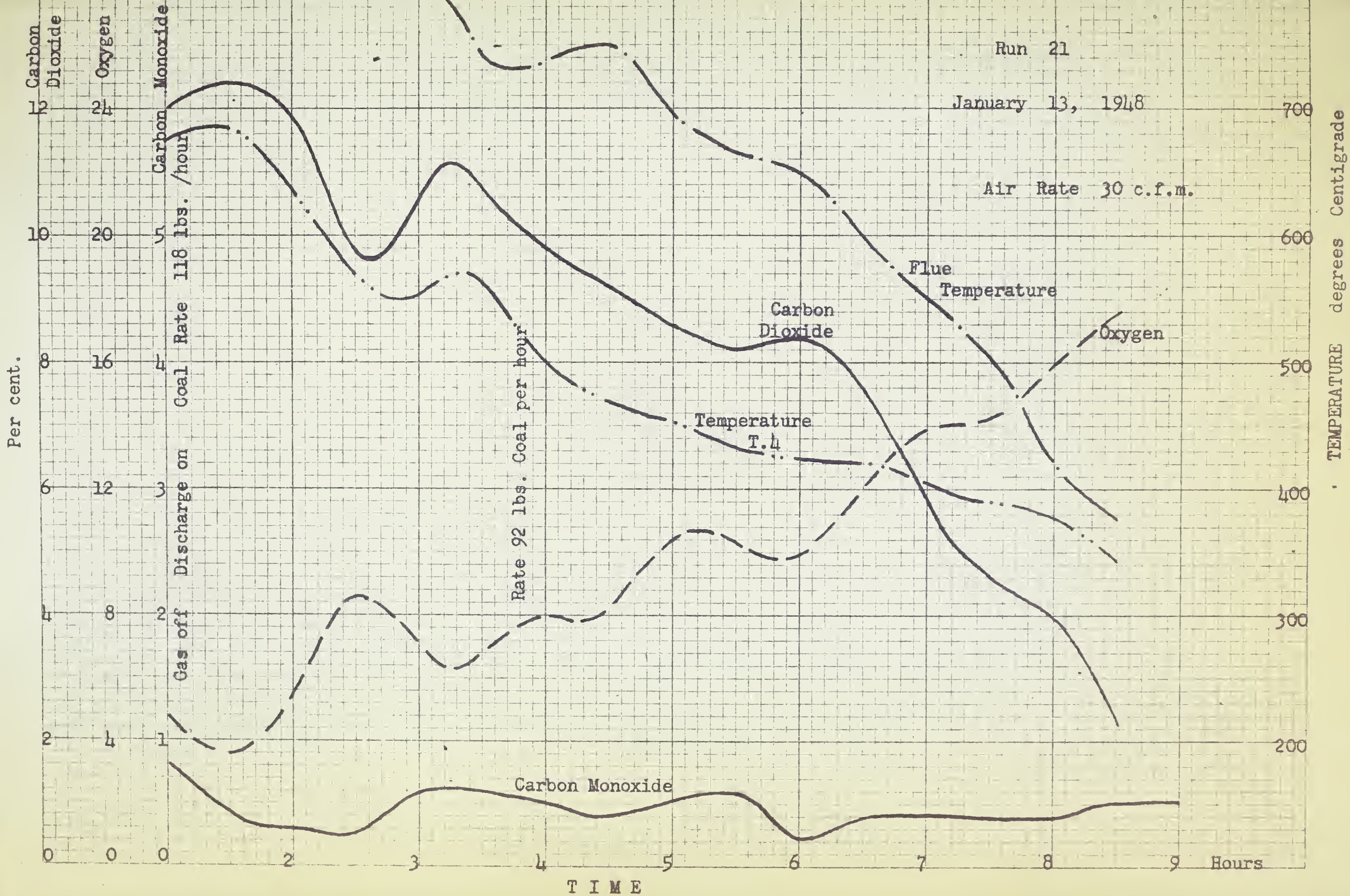
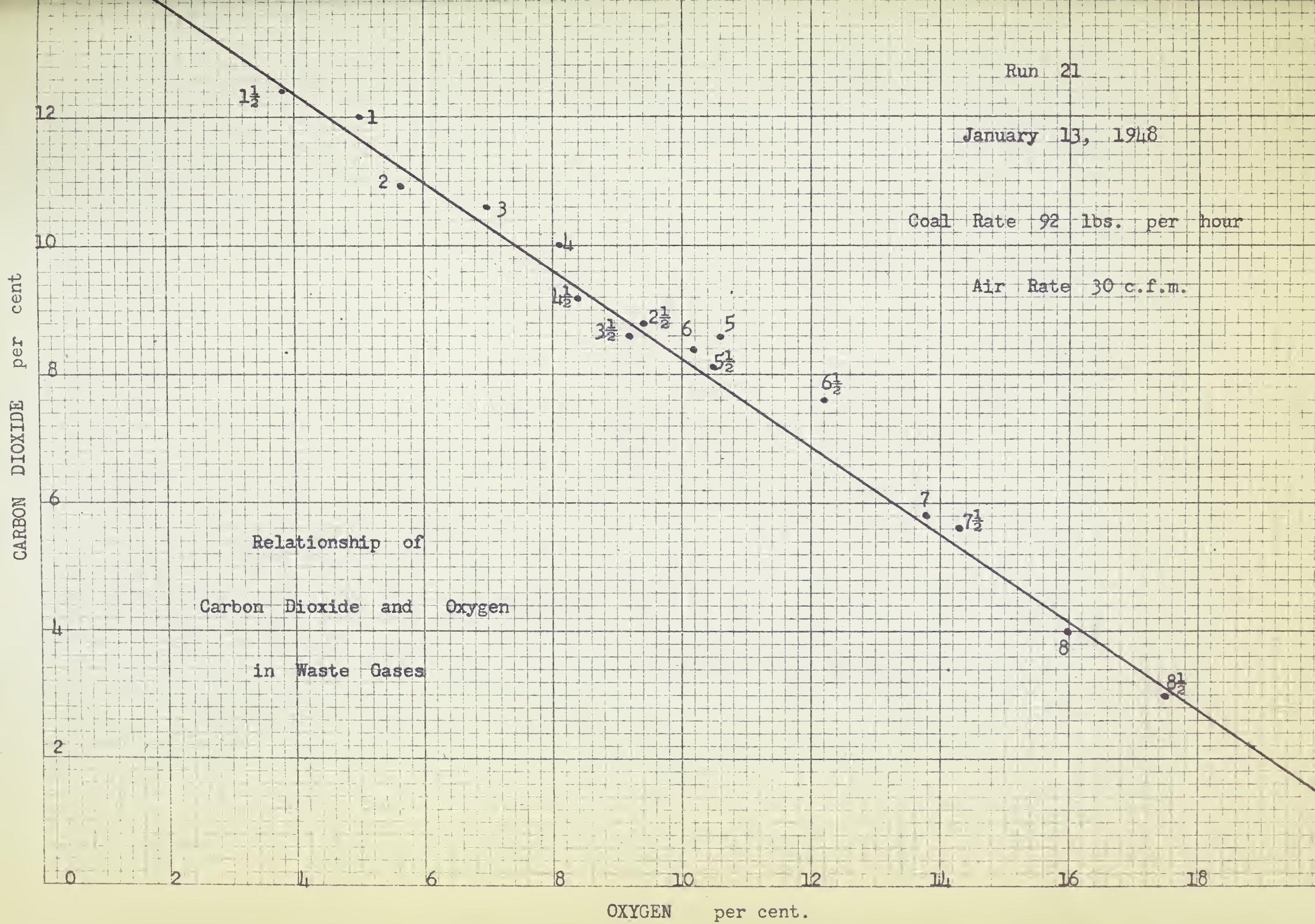

Run 21
January 13, 1948
Air Rate 30 c.f.m.
Carbon Dioxide
Oxygen
Carbon Monoxide
Per cent.
TEMPERATURE degrees Centigrade
Gas off Discharge on Coal Rate 118 lbs. /hour
Rate 92 lbs. Coal per hour
Flue Temperature
Carbon Dioxide
Temperature T.4
Oxygen
Carbon Monoxide
TIME
Hours
12
10
8
6
4
2
0
24
20
16
12
8
4
0
5
4
3
2
1
0
700
600
500
400
300
200
2
3
4
5
6
7
8
9

FIGURE XLIV



Run 21
January 13, 1948
Coal Rate 92 lbs. per hour
Air Rate 30 c.f.m.
Relationship of
Carbon Dioxide and Oxygen
in Waste Gases
CARBON DIOXIDE per cent
OXYGEN per cent.
0
2
4
6
8
10
12
14
16
18
1
1½
2
2½
3
3½
4
4½
5
5½
6
6½
7
7½
8
8½

FIGURE XLV

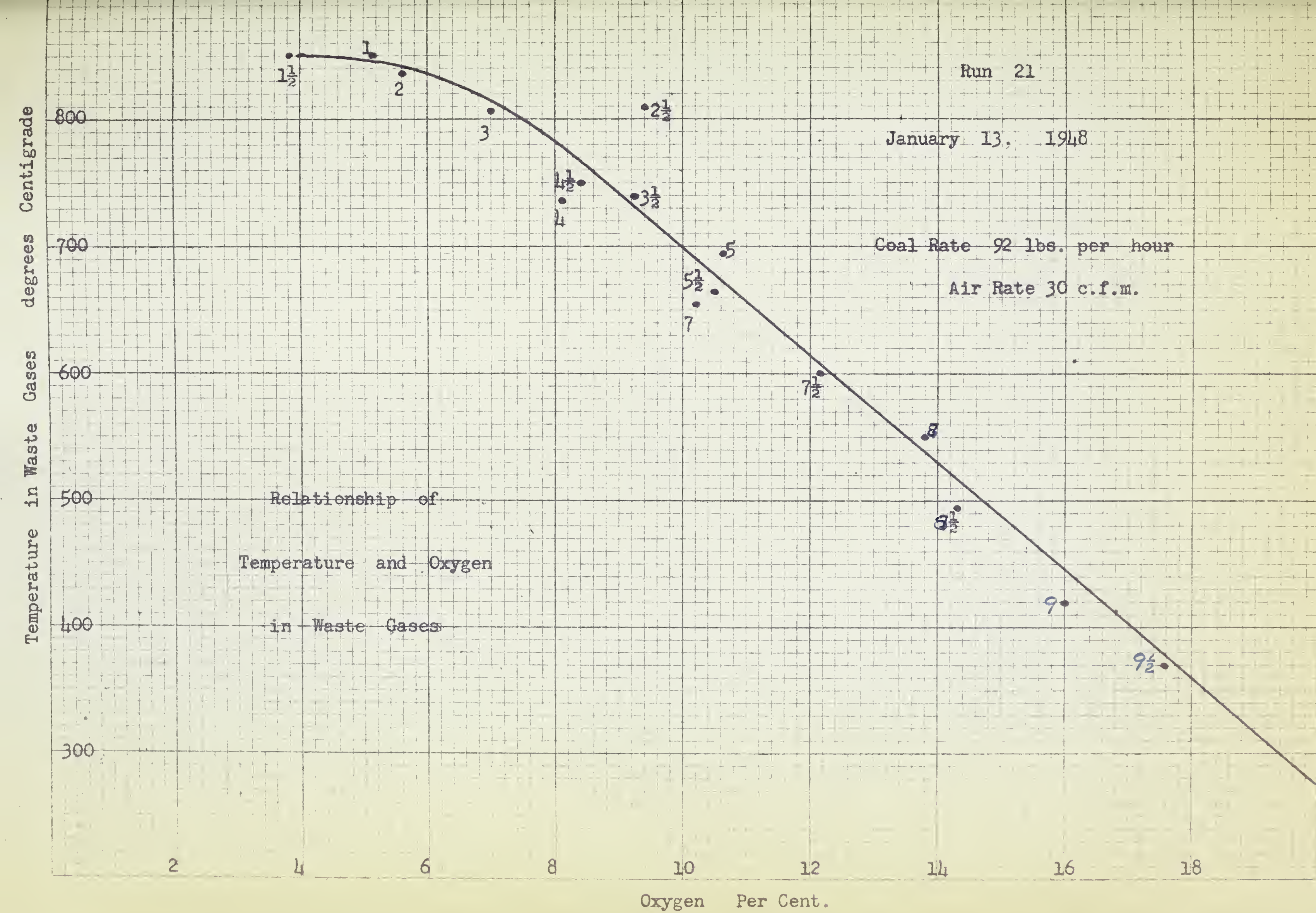

Run 21
January 13, 1948
Coal Rate 92 lbs. per hour
Air Rate 30 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
Temperature in Waste Gases degrees Centigrade
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18
Oxygen Per Cent.
1
$1\frac{1}{2}$
2
$2\frac{1}{2}$
3
$3\frac{1}{2}$
4
$4\frac{1}{2}$
5
$5\frac{1}{2}$
7
$7\frac{1}{2}$
8
$8\frac{1}{2}$
9
$9\frac{1}{2}$

FIGURE XLVI


Run 22
January 15, 1948
Coal Throughput 68 lbs. per hour
Air Rate 15 c.f.m.
Carbon Dioxide
Oxygen
Carbon Monoxide
Per Cent
12
10 20
8 16
6 12 3
4 8 2
2 4 1
0 0 0
2
3
4
5
6
7
8
9
TIME Hours
Flue Temperature
Carbon Dioxide
Temperature T.4
Oxygen
Carbon Monoxide
700
600
500
400
300
200
Temperature degrees Centigrade

FIGURE XLVII

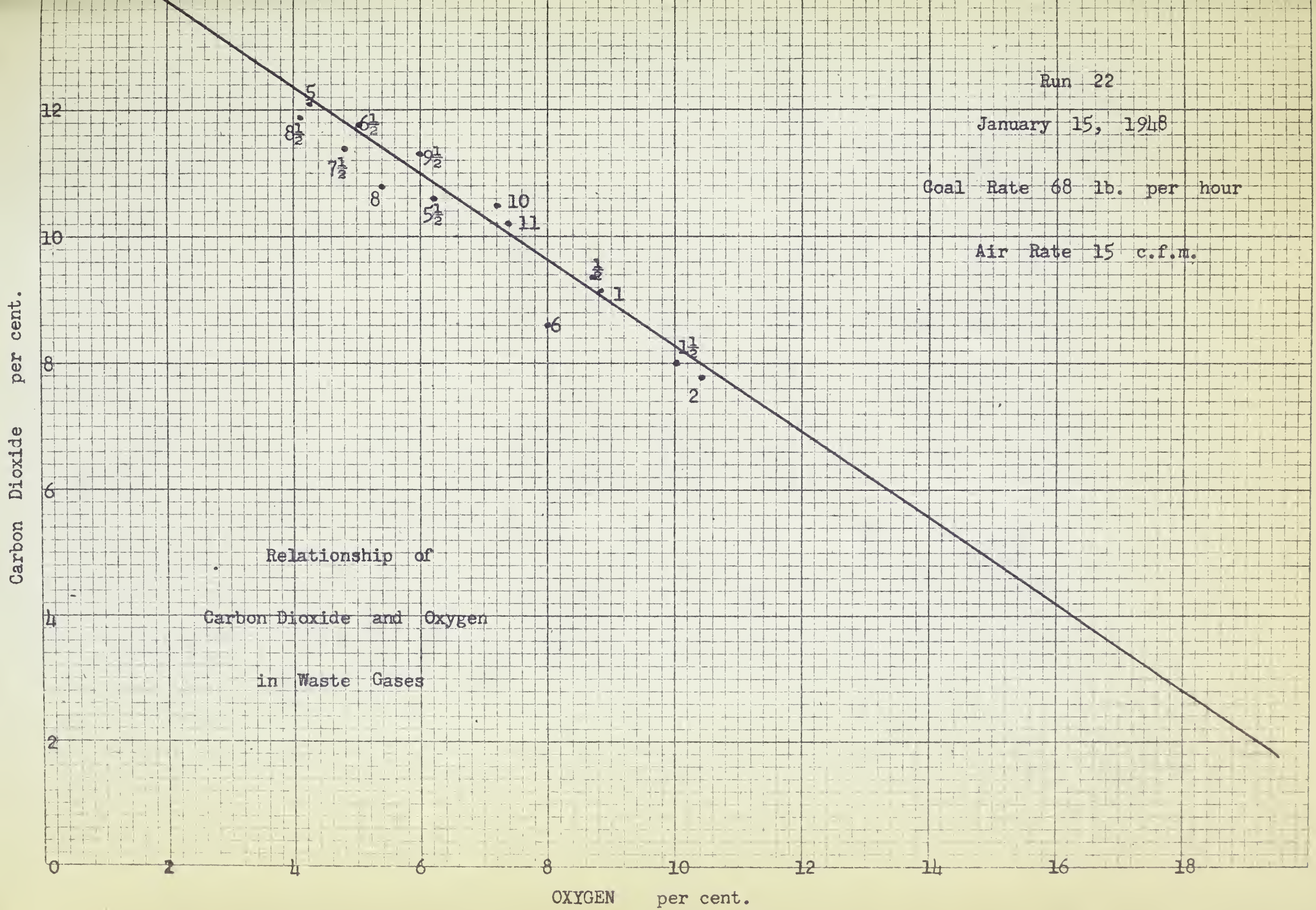
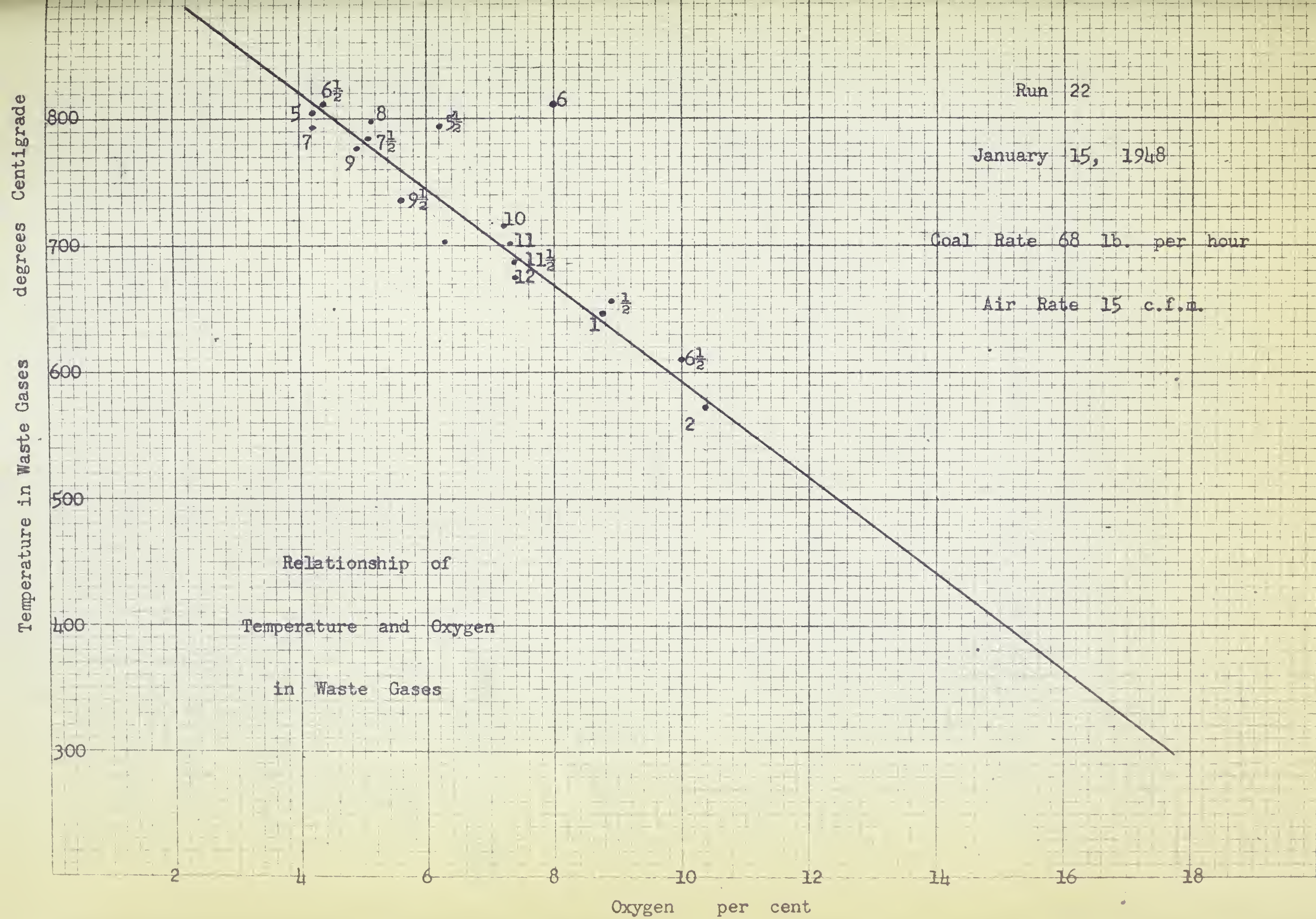

Run 22
January 15, 1948
Coal Rate 68 lb. per hour
Air Rate 15 c.f.m.
Relationship of
Carbon Dioxide and Oxygen
in Waste Gases
Carbon Dioxide per cent.
OXYGEN per cent.
0
2
4
6
8
10
12
14
16
18
5
$8\frac{1}{2}$
$6\frac{1}{2}$
$7\frac{1}{2}$
$9\frac{1}{2}$
8
$5\frac{1}{2}$
10
11
$\frac{1}{2}$
1
6
$1\frac{1}{2}$
2

FIGURE XLVIII


Run 22
January 15, 1948
Coal Rate 68 lb. per hour
Air Rate 15 c.f.m.
Relationship of
Temperature and Oxygen
in Waste Gases
Temperature in Waste Gases degrees Centigrade
Oxygen per cent
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18

D. SERIES IV

The ultimate composition and the calorific values of the coal used and of the char produced by carbonization of it in the pilot plant may be used to show the considerations which govern the continuous operation of the process. The analysis of the char obtained in Run No. 9 (Series 2, Page 93) may be employed for this purpose. The sample of char analysed represented the material obtained during the last one and one-half hours of operation during this run. The yield of char, as determined directly by weighing was 55.1 per cent. The data are given in Table XXXVIII.

TABLE XXXVIII

Compositions and Calorific Values of Coal and Char from Run 9

	Composition of Coal Per cent. by weight	Composition of Char Per cent. by weight
Carbon	47.9	70.55
Hydrogen	3.2	2.45
Oxygen	11.5	5.8
Nitrogen	1.3	1.2
Sulphur	0.4	0.4
Ash	10.8	19.6
Moisture	24.9	Nil
	100.0	100.00
Gross Calorific Value B.t.u. per lb.	8,210	11,500
Net Calorific Value B.t.u. per lb.	7,660	11,280
Yield of char, per cent. by weight of coal charged.	55.1	

During the carbonization process, there is consumed per pound of coal:

Carbon	0.479 - (0.551 x 0.7055) =	0.090 lb.
Hydrogen	0.032 - (0.551 x 0.0245) =	0.019 lb.
Nitrogen	0.013 - (0.551 x 0.0120) =	0.006 lb.
Sulphur	0.004 - (0.551 x 0.0040) =	0.002 lb.
Moisture		0.249 lb.
Oxygen	0.115 - (0.551 x 0.058) =	0.083 lb.

Omitting the sulphur, the amount of which is negligible, the oxygen and air requirements for the remaining elements, and the combustion products per pound of coal are given in the following table.

TABLE XXXIX

	Weight in lbs.	Lbs.		Combustion Products, lbs.			
		Oxygen	Air	Carbon Dioxide	Oxygen	Nitrogen	Water
Carbon	0.09	0.24	1.03	0.33	--	0.79	--
Hydrogen	0.019	0.15	0.66	--	--	0.51	0.17
Oxygen	0.083	--	--	--	0.083	--	--
Nitrogen	0.006	--	--	--	--	0.006	--
Ash	Nil	--	--	--	--	--	--
Moisture	0.249	--	--	--	--	--	0.249
		0.39	1.69	0.33	0.083	1.306	0.419
Oxygen used from coal		0.083	0.36	--	0.083	0.27	--
Total		0.307	1.33	0.33	--	1.036	0.419

The air required theoretically is 1.33 pounds per pound of coal carbonized. For every twenty per cent. in excess of this amount, i.e. for each 0.266 pounds above 1.33 pounds there will

appear in the combustion products

$$0.266 \times 0.232 = 0.0617 \text{ pounds of oxygen}$$

and $0.266 \times 0.768 = 0.204$ pounds of nitrogen

Then with varying amounts of excess air the weights of the products will be:

TABLE XL

Excess Air Per Cent.	Nil	20	40	60	80	100
Carbon Dioxide	0.33	0.33	0.33	0.33	0.33	0.33
Oxygen	Nil	0.062	0.124	0.186	0.248	0.310
Nitrogen	1.036	1.240	1.444	1.648	1.852	2.056
Water Vapor	0.419	0.419	0.419	0.419	0.419	0.419
Total Products	1.785	2.051	2.317	2.583	2.849	3.115

The percentages by weight of the combustion products are as follows:

TABLE XLI

Excess Air, Per Cent.	Nil	20	40	60	80	100
Carbon Dioxide	18.5	16.1	14.2	12.8	11.6	10.6
Oxygen	Nil	3.0	5.3	7.2	8.7	10.0
Nitrogen	58.1	60.4	62.4	63.8	65.0	66.0
Water Vapor	23.4	20.5	18.1	16.2	14.7	13.4
Total Products	100.0	100.0	100.0	100.0	100.0	100.0

On a dry basis the percentages by weight of the combustion products are:

TABLE XLII

Excess Air, Per cent.	Nil	20	40	60	80	100
Carbon Dioxide	24.2	20.3	17.3	15.3	13.6	12.2
Oxygen	Nil	3.8	6.5	8.6	10.2	11.5
Nitrogen	75.8	75.9	76.2	76.1	76.2	76.3
Total Products	100.0	100.0	100.0	100.0	100.0	100.0

The percentages by volume of the dry combustion products are:

TABLE XLIII

Excess Air, Per cent.	Nil	20	40	60	80	100
Carbon Dioxide	16.7	13.9	11.8	10.4	9.2	8.2
Oxygen	Nil	3.6	6.1	8.0	9.5	1017
Nitrogen	83.3	82.5	82.1	81.6	81.3	81.1
Total Products	100.0	100.0	100.0	100.0	100.0	100.0

Figure XLIX shows the relationship of the carbon dioxide in the combustion gases to the excess air quantities. In order to calculate the heat losses in the flue gases the mean specific heats of the water vapor and the dry combustion gases between 200°C. (392°F.) and 1000°C. (1832°F.) are taken respectively as 0.48 and 0.241.

The heat loss due to water vapor in the combustion gases = Weight of Water x ((212 - t) + 970 + 0.48 (T - 212)) B.t.u.

The heat loss in the dry chimney gases =

Weight of gas x (T - t) x 0.241 B.t.u.

Where T is the temperature of the exit gases

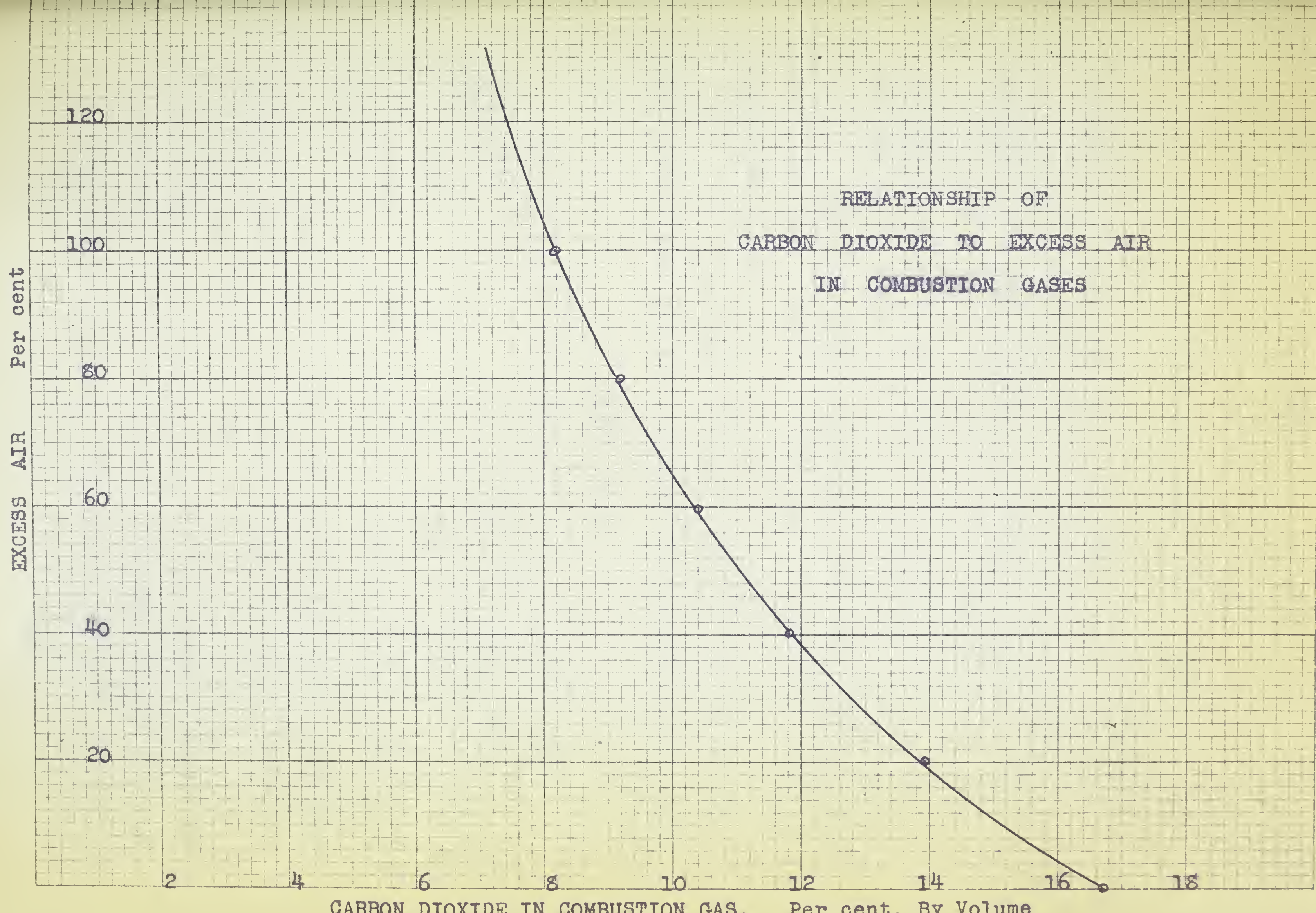
and t is the atmospheric temperature.

The total heat losses in the flue gases may now be calculated for flue gas temperatures of 200°C. and 1000°C respectively, with excess air quantities in stages of 20 per cent. up to 100 per cent. These calculations follow:

With theoretical air and with a waste gas temperature of 200°C., the heat loss in the water vapor =

0.419 (212 - 80 + 970 + 0.48 (392 - 212)) = 498 B.t.u.

FIGURE XLIX


RELATIONSHIP OF
CARBON DIOXIDE TO EXCESS AIR
IN COMBUSTION GASES
EXCESS AIR Per cent
120
100
80
60
40
20
2
4
6
8
10
12
14
16
18
CARBON DIOXIDE IN COMBUSTION GAS, Per cent. By Volume

At 1000°C. the heat loss in the water vapor

$$= 0.419\ (212 - 80 + 970 + 0.48\ (1832 - 212))$$

$$= 788\ \text{B.t.u.}$$

At 200°C. the heat loss in the dry gas

$$= 1.366\ (392 - 80)\ 0.241 = 103\ \text{B.t.u.}$$

At 1000°C. the heat loss in the dry gas

$$= 1.366\ (1832 - 80)\ 0.241 = 577\ \text{B.t.u.}$$

At 200°C. the total heat loss = 601 B.t.u.

At 1000°C. the total heat loss = 1365 B.t.u.

The heat loss in the water vapor will remain constant for a particular flue gas temperature whatever the amount of excess air used.

Similarly calculations for 20, 40, 60, 80 and 100 per cent. excess air give the quantities shown in Table XLIV.

TABLE XLIV

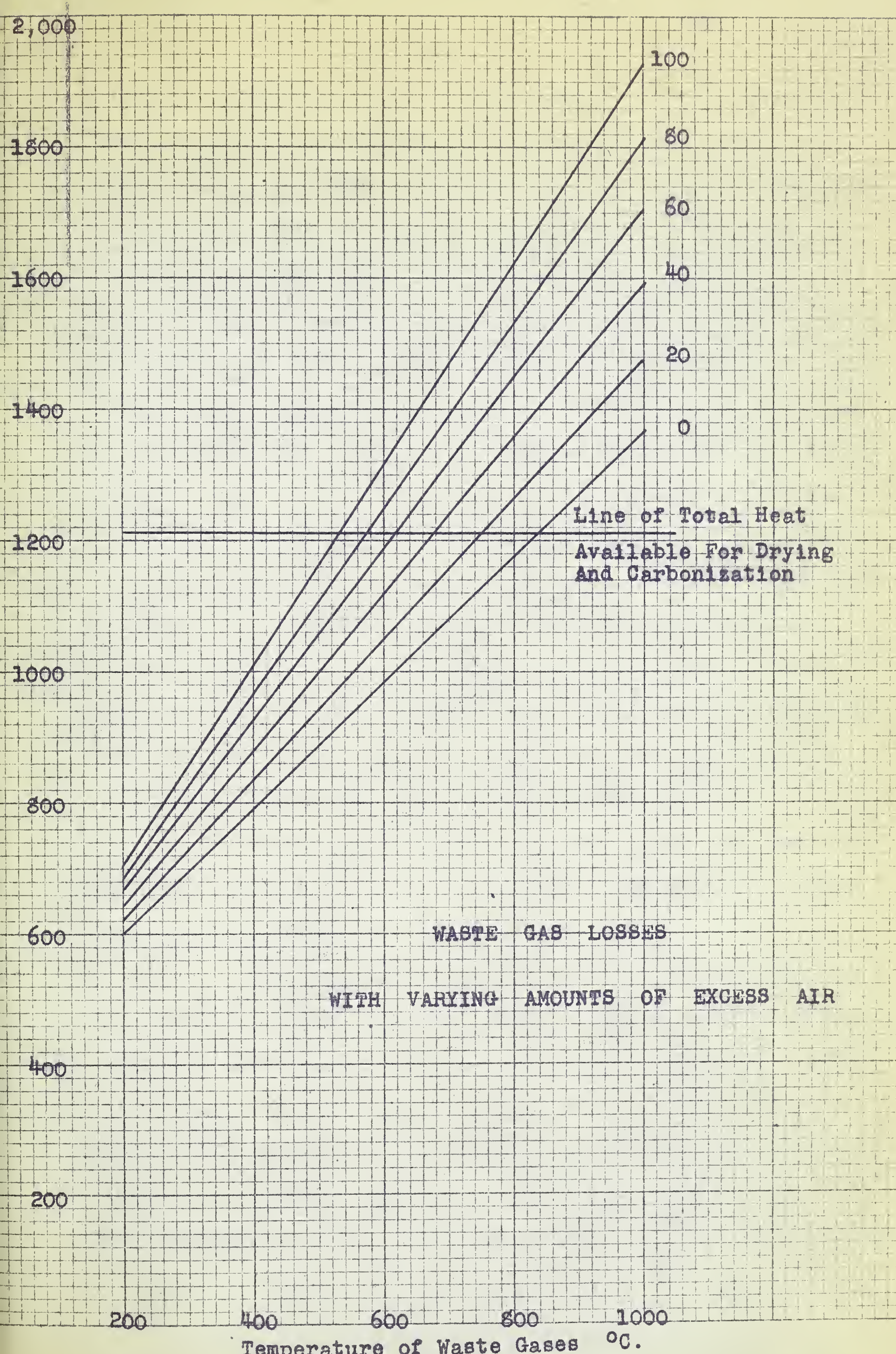
Heat Losses in Flue Gases at 200°C. and 1000°C. with Varying Amounts of Excess Air, B.t.u. per lb. Coal

Flue Exit Temperature °C	Excess Air Per Cent.					
	0	20	40	60	80	100
200°C.	601	621	641	661	681	701
1000°C.	1365	1477	1590	1702	1815	1927

Figure L shows the total heat loss in the flue gases plotted against the temperature of the flue gases for different quantities of excess air.

The total heat developed in the retort is equivalent to the net heat value of the coal less the net heat value of the char produced from it. Thus assuming complete combustion,

FIGURE L


2,000
1800
1600
1400
1200
1000
800
600
400
200
100
80
60
40
20
0
Line of Total Heat
Available For Drying
And Carbonization
WASTE GAS LOSSES
WITH VARYING AMOUNTS OF EXCESS AIR
200
400
600
800
1000
Temperature of Waste Gases °C.

the heat released per pound of coal carbonized equals $7660 - (0.551 \times 11280) = 1440$ B.t.u. Of the heat developed, a certain quantity is lost as sensible heat in the char, as radiation from the plant and as heat which may be required for carrying through the reactions during the actual carbonization of the coal. After allowance is made for these losses, the remaining heat can be divided between the heat required in the process and that passing out of the retort in the flue gases.

Efforts have been made to determine the extent of the former losses as accurately as possible. No heat is recovered as air preheat after the char enters the water jacketed cooler. If it is assumed that the temperature at which the char enters the cooler is 500°C. and that the mean specific heat of the char is 0.4 the sensible heat lost in the char is $(932 - 80)\ 0.4 \times 0.551 = 187$ B.t.u.

The radiation losses of the plant have been estimated to be 72 B.t.u. per lb. of coal carbonized at a coal throughput of 65 lbs. per hour.

It has already been mentioned that Hollings and Cobb have shown that with high oxygen containing coals, exothermic reactions occur at low temperatures of carbonization. Estimation of the actual amounts of heat generated by such reactions presents considerable difficulties. An examination of the literature indicates that according to the most careful measurements by Davis, Place and Edeburn (17) the exothermicity

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

of the kind of coal used in these carbonization experiments would amount to approximately 40 B.t.u. per lb. of dry coal or $\left(\frac{100 - 24.9}{100}\right) \times 40 = 30$ B.t.u. This quantity receives general confirmation from the results of experiments by Burke and Parry on the Heat Distillation of Various Types of Coal (18).

Summarizing, the total heat available in the carbonization of one pound of coal, assuming complete combustion of the volatile matter is thus

$$1440 - (187 + 72) + 30 = 1211 \text{ B.t.u.}$$

Figure L shows a relationship of the flue gas temperatue to the total heat loss in the flue gases with different quantities of excess air. Across the figure is drawn a line for 1211 B.t.u. per lb., which represents the total heat available for carbonization and drying. Any plant conditions which can be represented on the figure by a point above the line drawn across the figure will indicate conditions under which it is not possible for this plant to continue to operate since too great a quantity of heat is being lost in the flue gases and accordingly drying and carbonization cannot continue; for example, if, when the plant was approaching a steady state of carbonization the temperature of the waste gases was 800°C. and the amount of excess air was 20 per cent., then unless the waste gas temperature fell to a region of 650°C., the process must inevitably stop. An increase in the quantity of water in the coal will mean a depression of this line of total available heat so

that naturally a condition must arise eventually at which the plant ceases to function. The waste gases must, in any case, leave the plant at temperatures in excess of 212°F., that is above the dew point.

Although the actual rate of air supply may be varied, the temperature of the flue gases will obviously vary principally according to the calorific intensity of the combustion gases in the region of carbonization. Accordingly, it should be possible to draw a second line parallel to the heat loss in the flue gas axis, to the right of which will be represented a region in which the temperatures of carbonization will be such as to produce combustible gas and to the left of which, owing to the lower temperatures of carbonization and the consequent production of gas from the coal of high carbon dioxide content, combustion cannot occur in the customary plant conditions of air supply.

In order to obtain some estimate of the probable temperature in the carbonization zone, the Rosin IT diagram has been employed. Since this diagram is based on the net calorific value of the fuels it has seemed reasonable to use the net calorific value of the volatile matter, namely, 1440 B.t.u. per lb. coal and the dry flue gas quantities with different amounts of excess air. For different quantities of excess air it is possible to calculate the calorific intensities and to read the corresponding flame temperatures from the diagram.

From Table XL the weights of the dry products of combustion with the theoretical amount of air are:

Carbon Dioxide	0.33 lb.
Oxygen	Nil
Nitrogen	1.036 lb.
Total	1.336 lb.

The volumes at N.T.P. are:

Carbon Dioxide	0.33 x 8.11 = 2.68 cu. ft.
Nitrogen	1.036 x 12.81 = 13.28 cu. ft.
Total	15.96 cu. ft.

The Calorific Intensity

$$= \frac{1440}{15.96} = 90 \text{ B.t.u. per cu. ft.}$$

From the IT diagram the flame temperature is 1900°C.

The values for the Calorific Intensities and the flame tempratures may in this way be obtained for combustion gases when varying amounts of excess air are used. These are shown in Table XLV.

TABLE XLV

Calorific Intensities and Flame Temperatures with Varying Amounts of Excess Air

Quantity of Excess Air in Flue Gases Per cent.	Volume of Flue Gas per lb. coal Carbonized B.t.u./cu.ft. N.T.P.	Calorific Intensity B.t.u./cu.ft. N.T.P.	Flame Temperature °C.
0	15.95	90	1900
20	19.27	75	1700
40	22.52	64	1530
60	25.87	56	1360
80	29.16	49	1240
100	32.46	44	1140

The variation of the flame temperatures with varying amounts of excess air are shown in Figure LI.

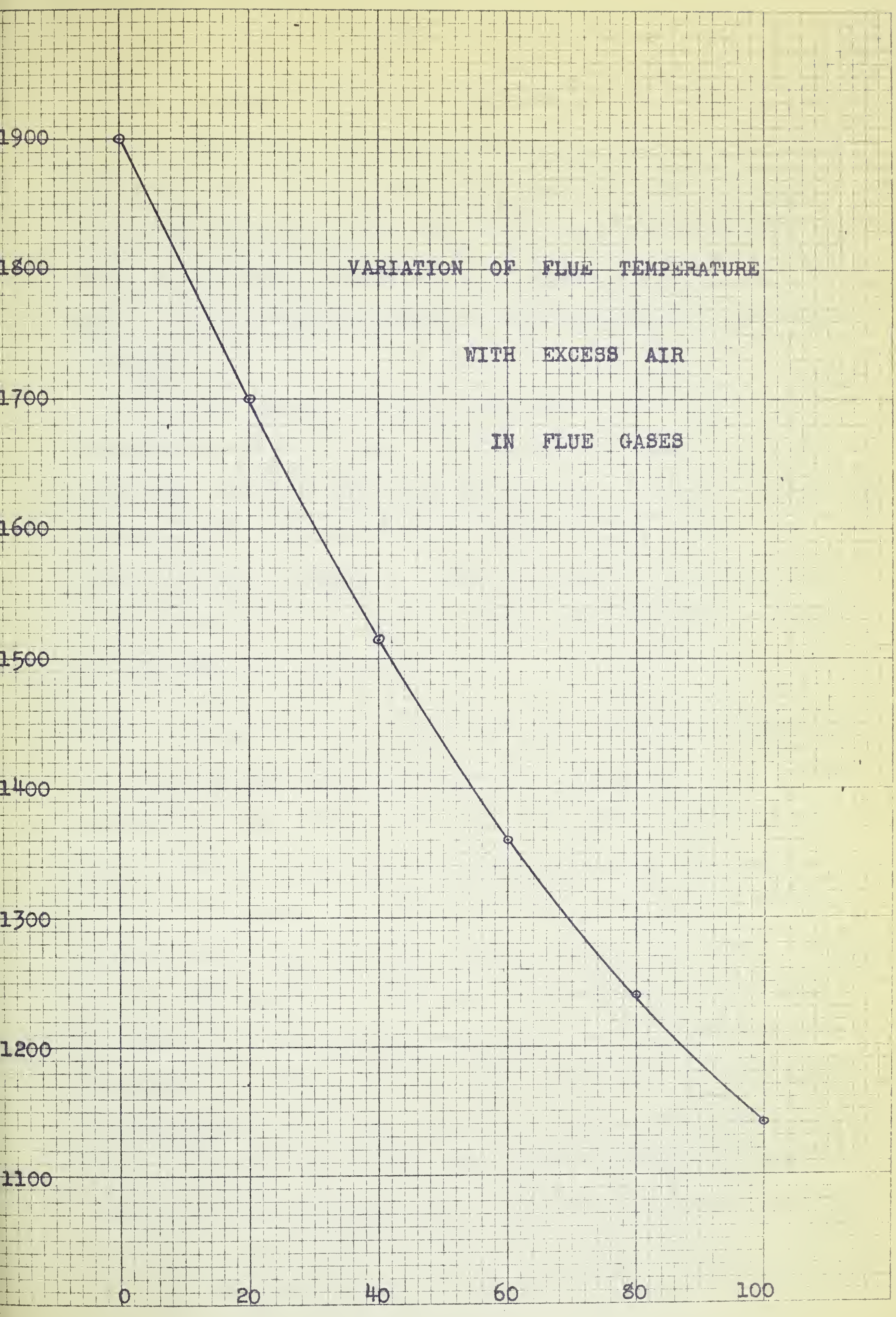
Since with larger quantities of excess air the flame temperatures are correspondingly lowered, if the carbon dioxide content of the flue gas continues to decrease, a condition must be reached when carbonization ceases more quickly than when a high percentage of the carbon dioxide in the flue gases is maintained. Under the latter conditions, heat transfer rates from hot gas to coal will be high and the actual rate of carbonization increased accordingly. The application of the above principles may be illustrated by considering them in relation to the results of the preceding runs.

For example, if Figure XLII from Run 20 be compared with Figure XLVIII from Run 22, whereas in the former case the percentage of excess air as indicated by the percentage of oxygen, varies only approximately between 12 and 14 per cent. in the latter case the variation is between approximately 4 and 10 per cent.

Referring to Figure L it will be seen, therefore, that in Run 22 the tendency is for a more pronounced movement towards the heat loss axis than in Run 20. In Run 20 the tendency is for the changing conditions to be represented to a greater degree along the lines representing the particular excess air quantity.

Generalizing the situation, therefore, one may say that unless there is close control of the quantity of excess

FIGURE LI


VARIATION OF FLUE TEMPERATURE
WITH EXCESS AIR
IN FLUE GASES
1900
1800
1700
1600
1500
1400
1300
1200
1100
0
20
40
60
80
100

air used in starting up the plant and in its continued operation, a condition may be reached represented by a position above the line of total available heat and with the temperatures of the waste gases such that the carbonization of the coal is no longer producing an adequate quantity of suitable gas. In this event stoppage of the carbonization process is inevitable.

If, however, there is control of the excess air quantities, whether these be well above what may be at the outset an economic rate, say 50 per cent., and the control is such as to be represented by descent along an excess air quantity line on Figure L, then presumably a condition will be attained below the line of total available heat at which the process will continue.

(a) In order to provide the most favorable conditions for testing out the above considerations on the plant it was decided, at this stage, to reduce the water content of the coal as much as existing facilities permitted and then to operate the plant, so adjusting the air supply that a high carbon dioxide content was present in the waste gases. Approximately 1700 pounds of coal were elevated on to the top of the boiler setting in the Power House and allowed to remain there for 36 hours. Unfortunately at the end of this period a slight quantity of the coal fired and the remainder had to be quickly removed and stored over night. A sample of the partially-dried material gave a moisture content of 16.6 per cent.

The coal rate and air rate at the commencement of run 23 were adjusted to give approximately 65 pounds per hour and 20 cubic feet per minute respectively. Measurement of the coal rate, from the start of discharge of the char over a period of three hours, showed a throughput of 77.7 lb. per hour. An adjustment to the discharge was made which gave a rate which was later measured as 67.2 lbs. per hour and this rate was then maintained for the remainder of the operating period.

A minimum carbon dioxide content of 10 per cent. was selected and adjustments of the air rate were made in steps from 20 c.f.m. to 15, 12 1/2, 7 1/2 and 5 respectively to maintain this quantity. Measurements of the air rate below 5 c.f.m. were difficult because of the limited calibration of the rotameter at the zero end of the scale. After the final setting of the air rate at 5 c.f.m. and of the discharge rate 20 minutes later, no further adjustments to the conditions of the plant were thought necessary. The results of this run are shown in Table XLVI and Figure LII.

It will be seen that after the final adjustments were made, apart from one rather sharp drop of two per cent. in the carbon dioxide content of the waste gases, the general tendency of the carbon dioxide content was to increase slightly over the last eight hours of the test. The carbon dioxide content over this period ranged approximately from ten to twelve per cent. representing an excess air quantity of 70 to 40 per cent.

After the attainment of a maximum some one and one-half hours after starting up the plant, the flue gas

TABLE XLVI

Trial Run No. 23 January 27, 1948.
Coal throughput 67.2 lbs. per hour. Air Rate from 20 to 5 c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½	3	3½
	Temperature °C.						
4	654	692	678	636	615	568	552
5	170	225	424	440	454	461	460
6	36	31	84	455	472	480	482
7	850	910	953	994	953	953	974
8	850	910	953	968	910	905	882
	Per Cent. in Waste Gases						
Carbon Dioxide	8.4	11.3	11.4	14.0	13.0	11.0	9.4
Oxygen		4.3	3.8	1.9	2.6	4.6	7.0
Carbon Monoxide		1.2	0.6	0.7	0.4	0.8	0.6

	4	4½	5	5½	6	6½
4	552	556	560	558	566	570
5	474	472	480	486	482	494
6	509	504	504	506	504	516
7	765	720	630	630	630	630
8	765	690	630	640	660	630
Carbon Dioxide	10.4	11.8	7.8	9.8	8.9	9.2
Oxygen	5.6	5.4	10.2	6.6	5.5	6.0
Carbon Monoxide	1.2	2.0	1.4	1.8	2.0	1.7

	7	7½	8	8½	9	9½
4	570	566	563	557	540	562
5	498	506	502	490	494	488
6	514	502	514	502	497	494
7	560	540	500	475	470	470
8	612	550	550	570	510	510
Carbon Dioxide	8.8	10.0		10.6	8.8	10.8
Oxygen	5.6	6.2		6.0	6.2	6.4
Carbon Monoxide	2.4	1.3		1.6	1.0	1.8

	Time after charging, Hours					
	10	10½	11	11½	12	12½
T.C. Number	Temperature °C.					
4	566	563	568	563	559	561
5	488	492	502	499	502	502
6	494	511	502	509	502	498
7	445	430	420	415	400	410
8	490	490	470	445	425	410
	Per cent. in Waste Gases					
Carbon Dioxide	10.8	11.0	11.2	11.4	10.8	10.9
Oxygen	5.3	6.0	6.4	6.2	6.6	6.5
Carbon Monoxide	1.6	1.7	1.2	1.4	1.0	1.1
	13	13½	14	14½	15	15½
4	563	563	545	563	567	564
5	509	506	513	511	521	528
6	509	506	499	514	494	504
7	390	380	380	400	415	400
8	390	380	380	360	350	340
Carbon Dioxide	11.2	11.2	11.9	12.2	11.6	11.4
Oxygen	6.4	6.2	5.3	5.0	5.6	6.0
Carbon Monoxide	1.2	1.0	1.3	1.2	1.0	1.0

Remarks:

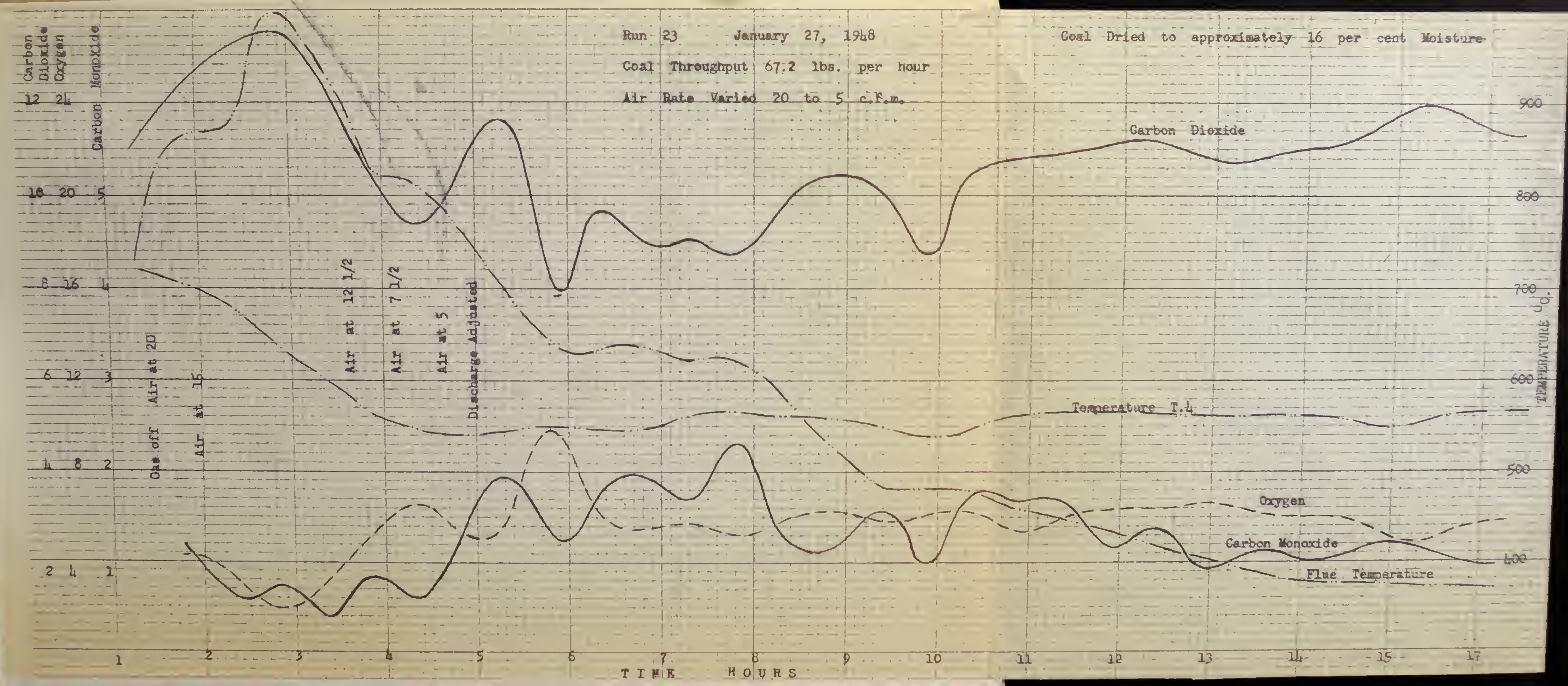
Yield of Char: 66.2 per cent.
Char Sample No. 607-48
Air - Coal Ratio: 4.5 cu. ft. air per lb. coal

Proximate Analysis of Char:

	Per cent.
Ash	22.0
Volatile Matter	9.8
Fixed Carbon	68.2
	100.0

Calorific Value, B.t.u. per lb. 11,210

FIGURE LII


Run 23 January 27, 1948
Coal Throughput 67.2 lbs. per hour
Air Rate Varied 20 to 5 c.f.m.
Coal Dried to approximately 16 per cent Moisture
Carbon Dioxide
Oxygen
Carbon Monoxide
Carbon Dioxide
Temperature T.4
Oxygen
Carbon Monoxide
Flue Temperature
Gas off
Air at 20
Air at 15
Air at 12 1/2
Air at 7 1/2
Air at 5
Discharge Adjusted
TEMPERATURE °C.
TIME HOURS

temperature fell consistently over a period of about twelve hours, with the exception of relatively short periods during which the temperatures remained approximately constant due probably, to the adjustment of air and discharge rates. Over approximately the last three hours of the run the flue gas temperature was substantially constant at 380°C. Over this period also, there was present in the waste gases slightly more than one per cent. carbon monoxide. The temperatures as measured by T4 remained substantially constant during this time.

Figure LIII, relating the percentage of oxygen to carbon dioxide in the waste gases shows that the points representing the various readings are grouped in the area from five to seven per cent. oxygen and ten to twelve per cent. carbon dioxide.

Figure LIV shows the relation of the excess air to the flue temperature.

Since the flue temperatures over the period of the run, following the plant adjustments, fell steadily in the region of about six per cent. oxygen, not only over this period is the condition following substantially the line on Figure L representing 50 per cent. excess air, but the end conditions of carbonization as shown by Figure L represents an accumulation of available heat in the carbonizer in excess of the total heat required for carbonizing and drying.

Reference to Figure LI suggests that the temperature in the vicinity of the carbonization zone is in the neighborhood of 1250°C. With the amount of heat in excess of that

FIGURE LIII

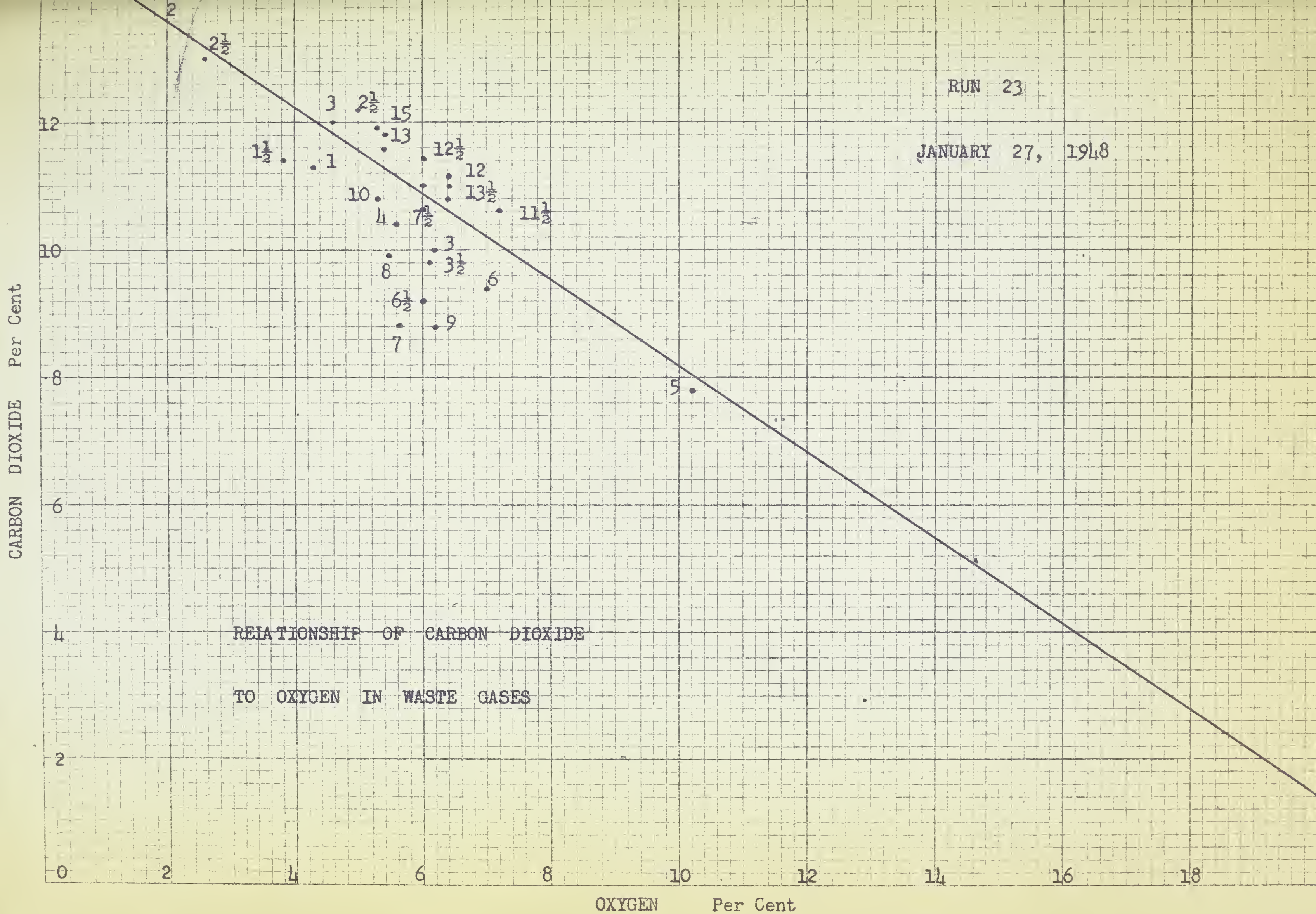
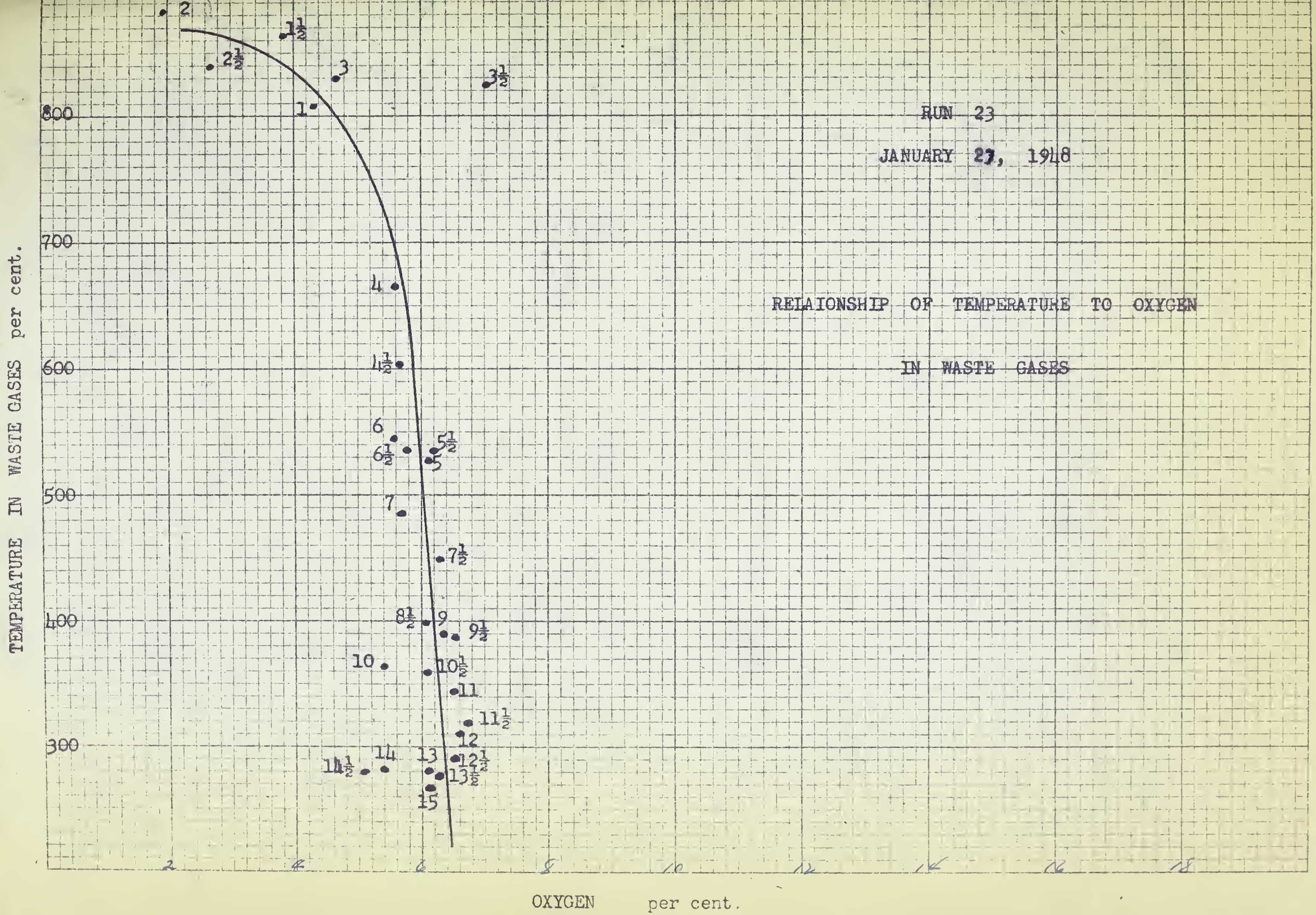

RUN 23
JANUARY 27, 1948
RELATIONSHIP OF CARBON DIOXIDE
TO OXYGEN IN WASTE GASES
CARBON DIOXIDE Per Cent
OXYGEN Per Cent

FIGURE LIV


RUN 23
JANUARY 27, 1948
RELAIONSHIP OF TEMPERATURE TO OXYGEN
IN WASTE GASES
TEMPERATURE IN WASTE GASES per cent.
OXYGEN per cent.
800
700
600
500
400
300
2
4
6
8
10
12
14
16
18

required for the process, presumably increasing quantities of volatile matter are being evolved from the coal, and the excess air is being correspondingly reduced as shown by the increasing carbon dioxide content of the gas. The temperature in the flue in the vicinity of carbonization is slowly increasing despite the fact that over a considerable period of the run the waste gas temperature is falling.

This run, in which operating conditions were reasonably steady for the last ten hours of operation, indicated that at least with partially dried coal, carbonization in this retort could be maintained for that length of time. The plant was shut down because of the limited quantity of partially dried coal and because no provision was made to operate the retort continuously.

(b) The successful operation of the retort in the preceding run, using partially-dried coal made desirable a run under similar conditions using the coal in the undried condition. The intention throughout was again to maintain the carbon dioxide content of the flue gas at a minimum of ten per cent. The results of the run are shown in Table XLVII and Figure LV.

With an air rate initially at 25 c.f.m. and reduced after one and one half hours to 12.5 c.f.m. the carbon dioxide content of the waste gases averaged about 12 per cent for six hours but thereafter this increased slowly and when the plant was eventually shut down it had reached 14 per cent. The measured throughput rate, over a period of three hours, was 65 pounds per hour but it must be understood that this simply

TABLE XLVII

Trial Run No. 24 February 10, 1948.
Coal throughput 65 lbs. per hour. Air Rate from 25 to 12½ c.f.m.

Time after charging, Hours

T.C. Number	½	1	1½	2	2½	3
	Temperature °C.					
4	798	752	664	635	610	593
5	314	510	483	464	460	457
6	62	127	462	438	440	443
7	911	972	968	957	946	942
8	870	942	924	901	888	850
	Per cent. in Waste Gases					
Carbon Dioxide	12.6	11.6	10.8	12.2	12.2	12.0
Oxygen	1.0	3.0	3.7	2.8	1.8	2.7
Carbon Monoxide	1.7	2.9	2.7	1.4	2.8	2.3

	3½	4	4½	5	5½	6
4	574	550	532	522	512	497
5	468	454	452	438	438	434
6	468	454	462	452	450	434
7	868	835	827	818	806	790
8	806	786	786	786	786	770
Carbon Dioxide	12.6	12.2	11.6	12.0	12.2	11.6
Oxygen	2.4	2.6	2.6	3.2	3.7	3.2
Carbon Monoxide	2.2	2.4	2.4	2.0	2.8	2.2

	6½	7	7½	8	8½
4	494	492	486	480	483
5	434	426	424	419	422
6	438	438	430	428	428
7	780	780	780	780	780
8	745	750	745	740	730
Carbon Dioxide	12.5	12.8	12.4	12.0	13.3
Oxygen	3.2	2.6	3.0	3.7	2.1
Carbon Monoxide	1.7	1.8	1.6	1.5	1.6

T.C. Number	9	9½	10	10½	11
	Temperature °C.				
4	485	480	476	474	471
5	419	428	419	412	415
6	431	438	434	428	424
7	780	765	765	710	750
8	730	715	710	730	710
	Per cent. in Waste Gases				
Carbon Dioxide	13.1	13.6	12.4	12.2	12.4
Oxygen	3.3	2.2	2.6	2.7	3.0
Carbon Monoxide	1.4	1.4	1.9	1.1	1.6

Time after charging, Hours

	11½	12	12½	13	13½
4	462	452	457	455	455
5	410	410	410	410	410
6	428	422	426	426	426
7	740	745	750	750	752
8	690	710	710	710	700
Carbon Dioxide	12.0	12.8	14.4	14.2	13.8
Oxygen	3.0	2.4	1.5	1.6	2.0
Carbon Monoxide	1.4	2.2	1.2	1.2	1.4

Remarks:

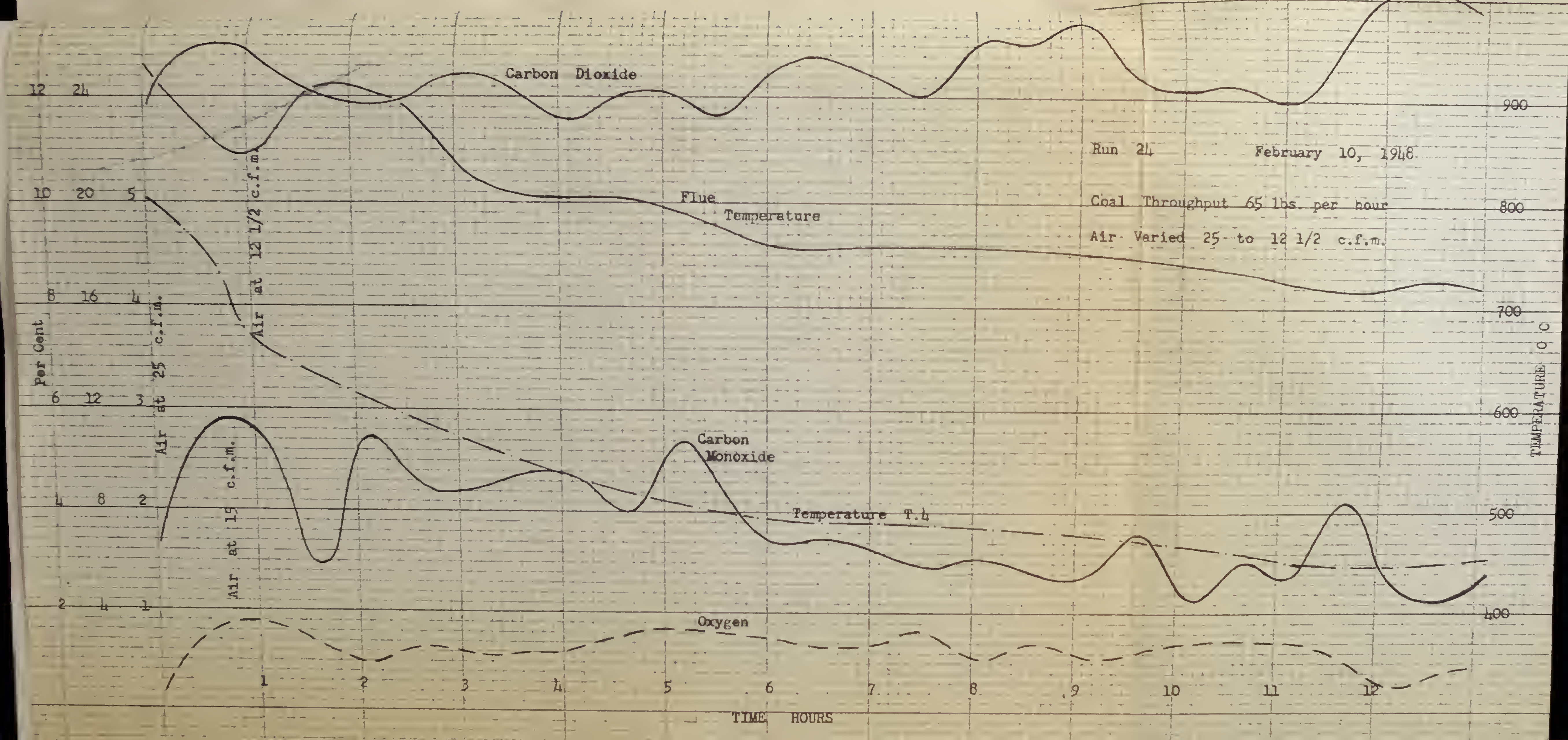
Yield of Char: 52 per cent.
Char Sample No. 608-48
Air - CoalRatio: 1.5 cu. ft. air per lb. coal.

Proximate Analysis of Char

	Per cent.
Ash	21.6
Volatile Matter	10.0
Fixed Carbon	68.4
	100.0

Calorific Value, B.t.u. per lb. 11,240

FIGURE LV



Carbon Dioxide
Run 24
February 10, 1948
Flue
Temperature
Coal Throughput 65 lbs. per hour
Air Varied 25 to 12 1/2 c.f.m.
Per Cent
Air at 25 c.f.m.
Air at 12 1/2 c.f.m.
Air at 19 c.f.m.
Carbon
Monoxide
Temperature T.4
Oxygen
TEMPERATURE ° C
12 24
10 20 5
8 16 4
6 12 3
4 8 2
2 4 1
900
800
700
600
500
400
1 2 3 4 5 6 7 8 9 10 11 12
TIME HOURS

represents an average figure and fluctuations in the rate of discharge over the whole period of the run may have been considerable.

From Figure LV it will be seen that the flue gas temperature in this run was about 160°C. higher than in Run 23, a result which was not anticipated and for which, at the present stage of investigation, no explanation is offered. As in Run 23, the plant worked quite satisfactorily until it was shut down at the end of the day's run.

E. SERIES V

Up to this time no provisions had been made to operate the plant for periods exceeding about 15 hours. Arrangements were later made to operate the plant for as long as seemed necessary to determine, under the limitations of plant operation,

(a) The effects of increasing regularly the quantities of excess air and

(b) the effects of the variations in the rate of throughput of the coal through the retort by varying the speed of the char extractor.

(a) <u>Run 25</u>

In this run, the rate of excess air quantities, as determined by the percentage of carbon dioxide in the flue gases was varied as far as possible in a regular manner.

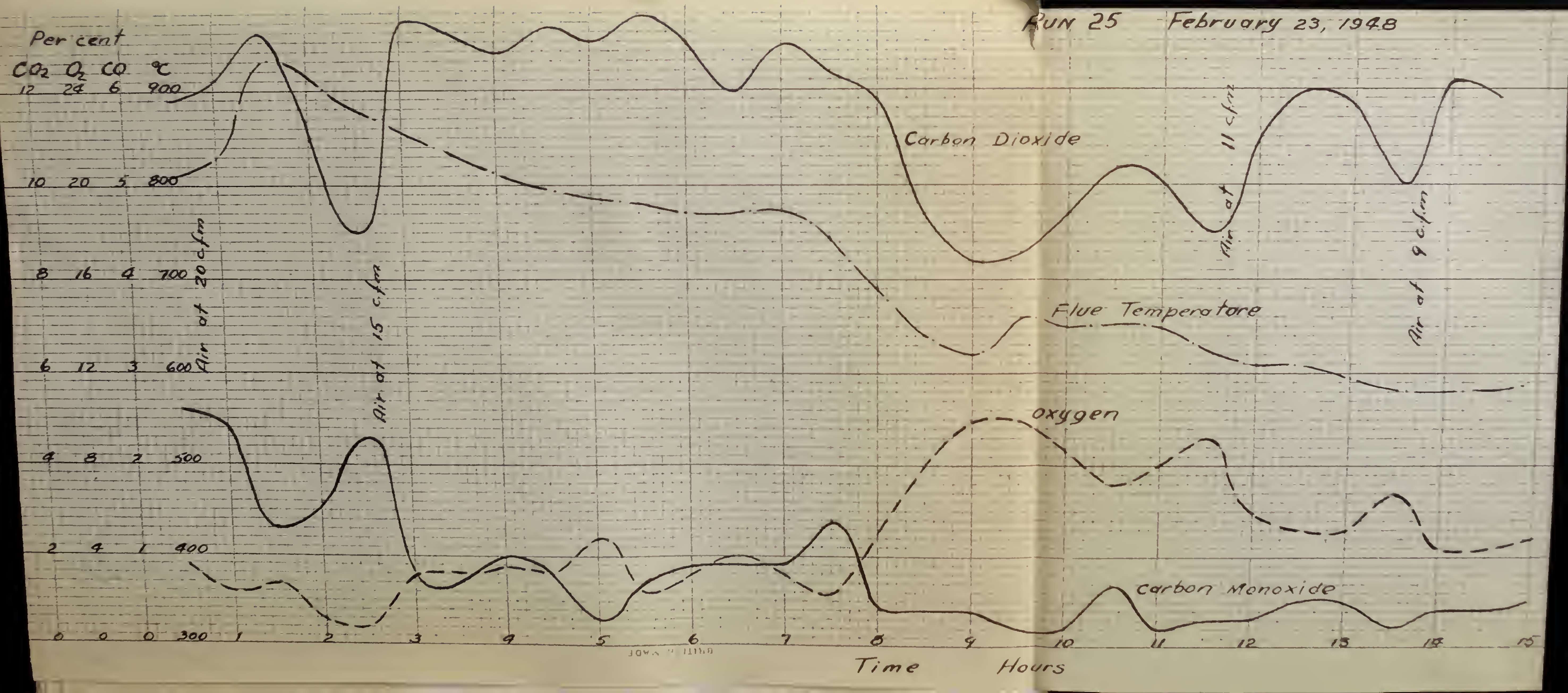
At the outset it was decided to operate with the carbon dioxide in the waste gases in excess of ten per cent., i.e. with an excess air quantity less than about 70 per cent.

Reference to Figure L shows that with a flue gas temperature of approximately 600°C. 70 per cent excess air represents the maximum excess air quantity allowable for plant operation. Since a throughput rate of approximately 70 pounds per hour had been shown with both partially-dried and undried material to be satisfactory over a working day, this rate was decided on for a long period run.

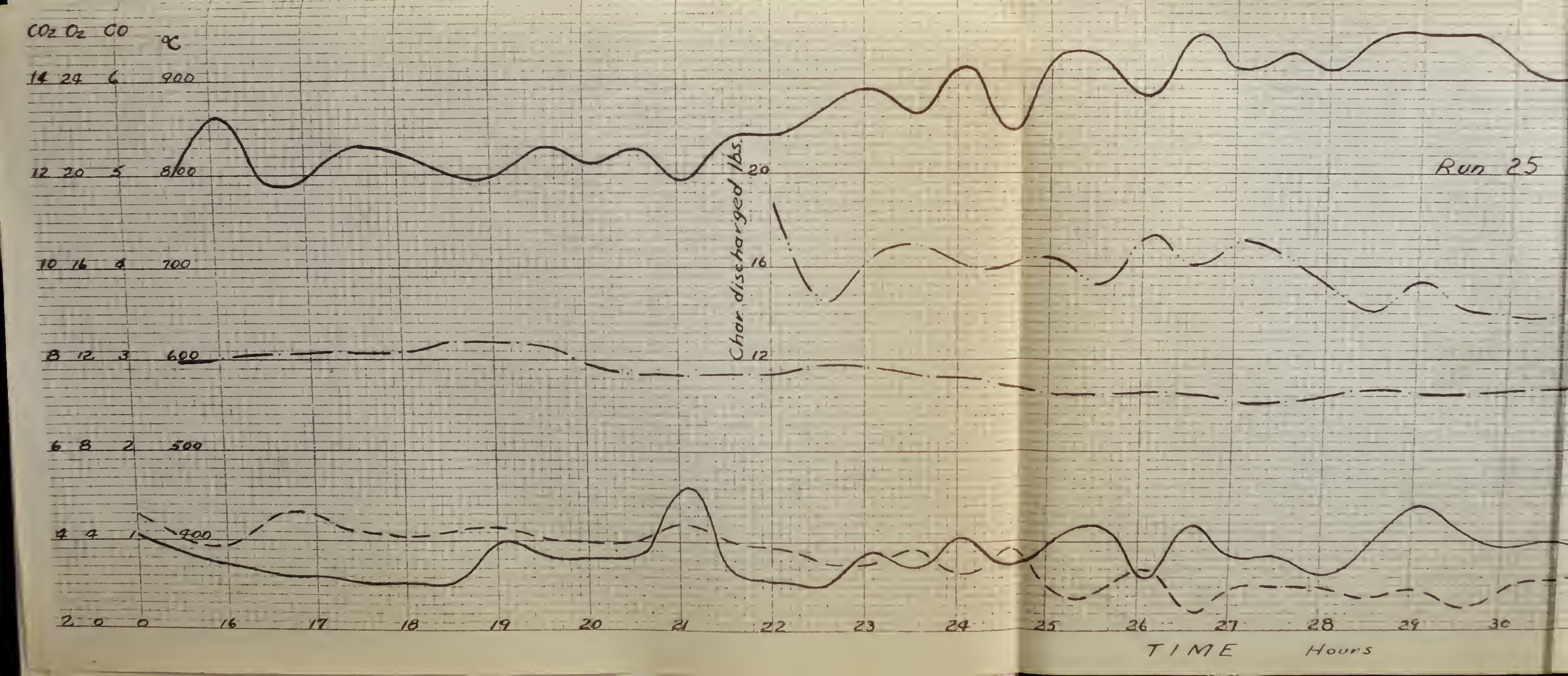
The period of time from the starting up to the shutting down of the plant was 76 hours. During the test, half-hourly readings were taken of the flue gas temperatures and of the temperatures in the coal stream as measured by T4, 5 and 6. The flue gases were analyzed every half hour for carbon dioxide, oxygen and carbon monoxide contents. After a period of 21 hours, when it was considered that steady operational conditions had been obtained, measurements were made of the weight of char every half hour. Samples of char were taken immediately preceding the alteration of the air supply as representative of the char produced during a period with a selected air supply.

Eventually, some hours before shutting down the plant, the air supply was greatly increased and under these conditions, prior to the conclusion of the run, the flames expired in one of the flues as has already been reported as occurring in earlier experiments. Throughout the whole period of the run the pressures in the retort were maintained substantially constant. Since actual readings taken during the test are very numerous, these are not recorded in the thesis but are presented graphically in Figure LVI.

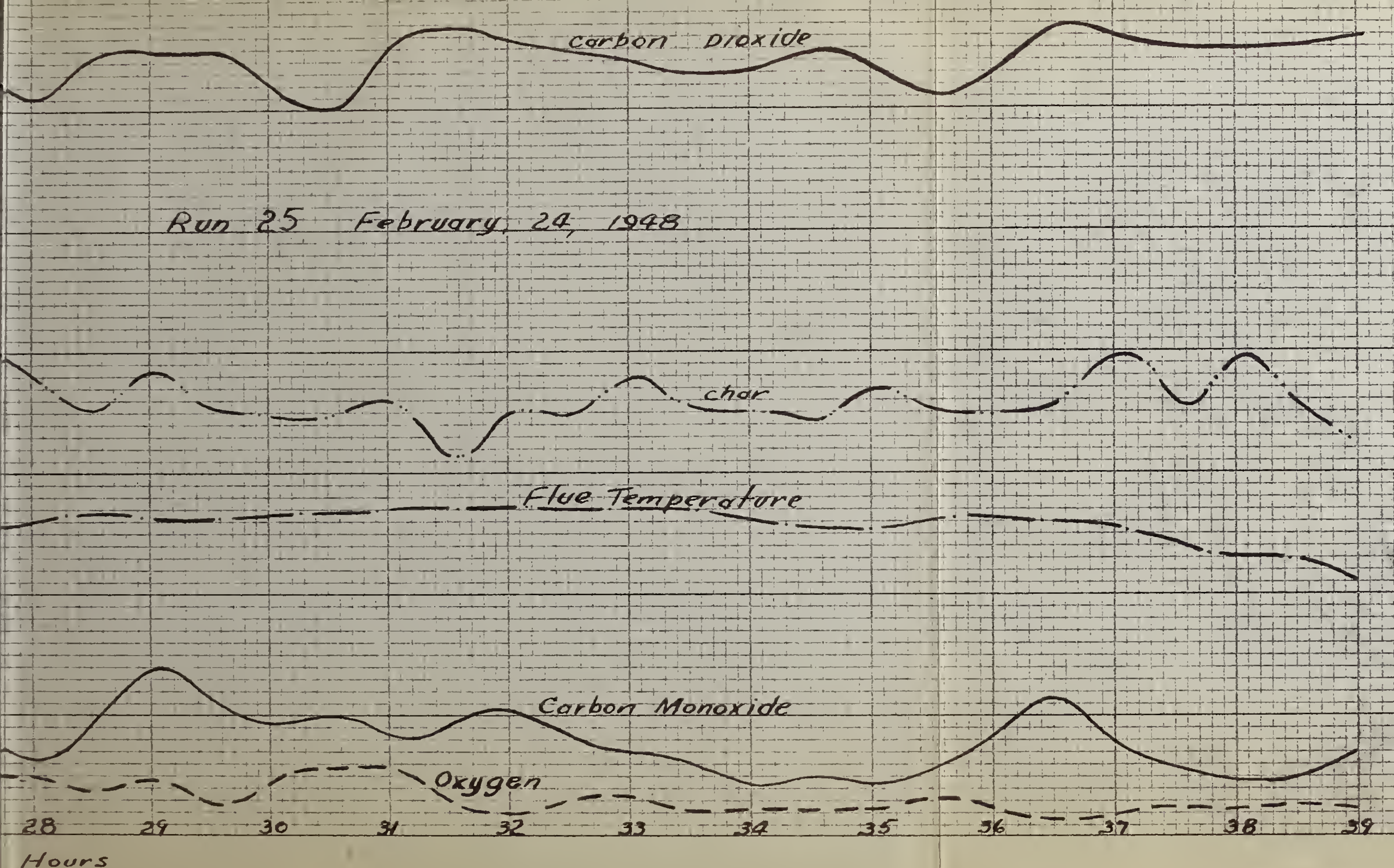
FIGURE LVI

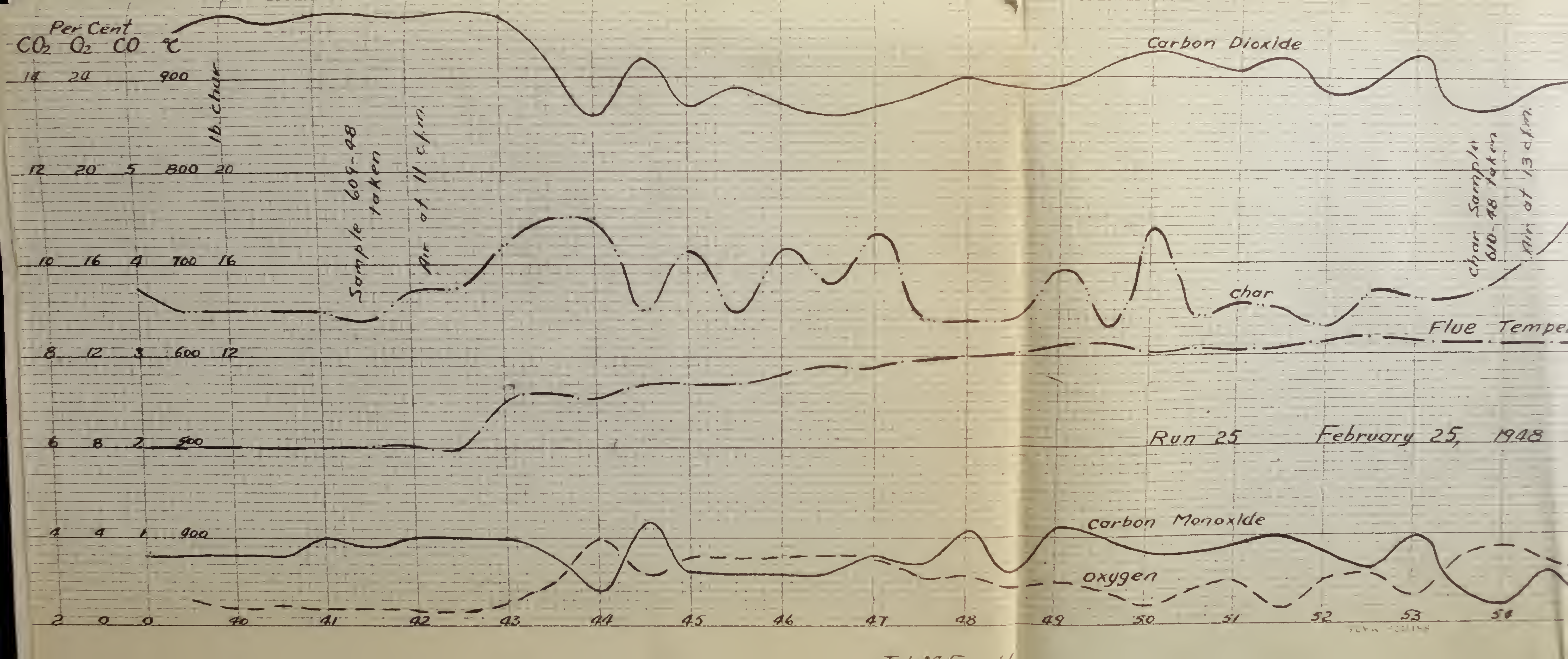


RUN 25 February 23, 1948
Per cent
CO_2 O_2 CO °C
12 24 6 900
10 20 5 800
8 16 4 700
6 12 3 600
4 8 2 500
2 4 1 400
0 0 0 300
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Time Hours
Carbon Dioxide
Flue Temperature
Oxygen
Carbon Monoxide
Air at 20 c.f.m
Air at 15 c.f.m
Air at 11 c.f.m
Air at 9 c.f.m

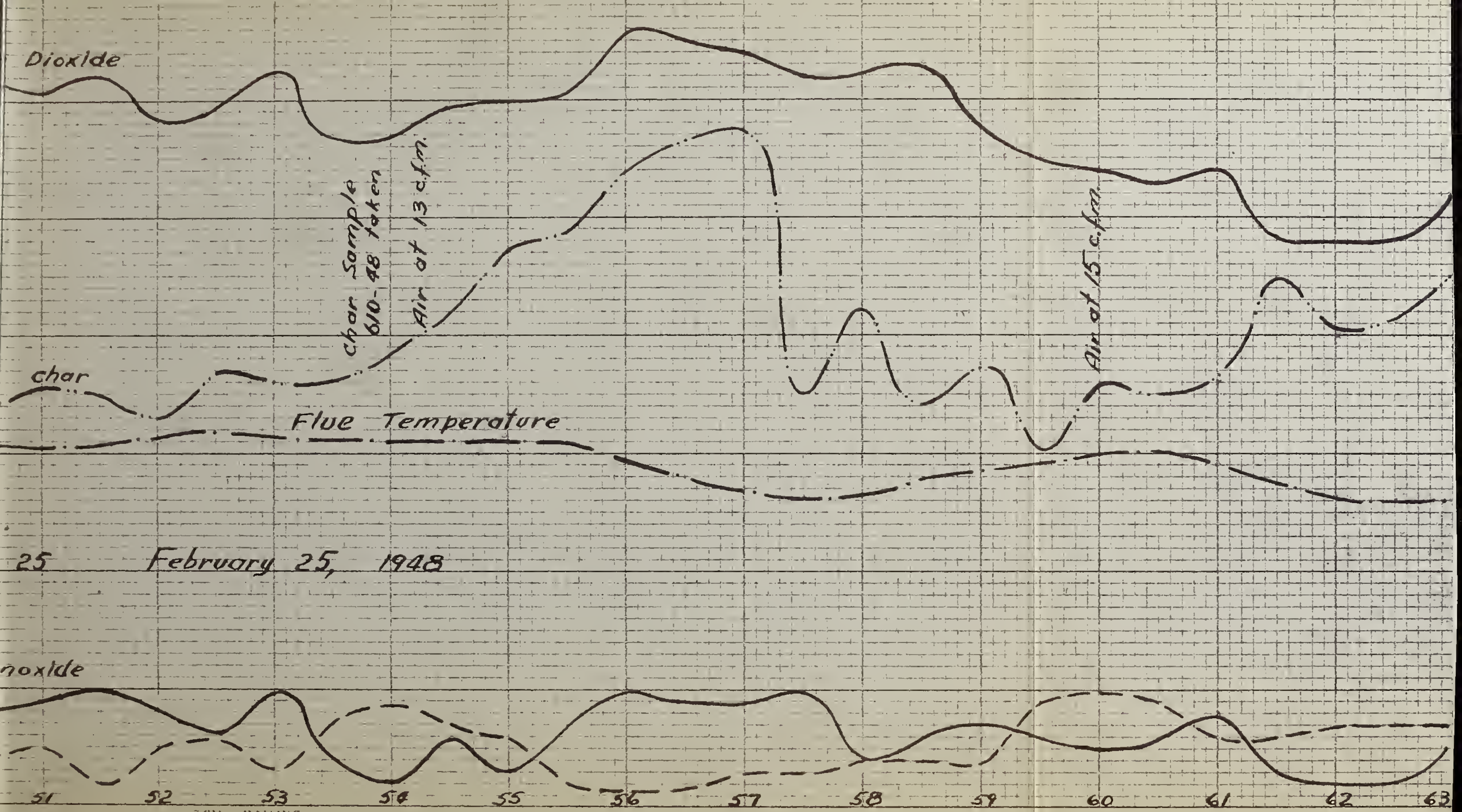


CO2 O2 CO
°C
14 24 6 900
12 20 5 800
10 16 4 700
8 12 3 600
6 8 2 500
4 4 1 400
2 0 0
Char discharged lbs.
20
16
12
Run 25
16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
TIME Hours

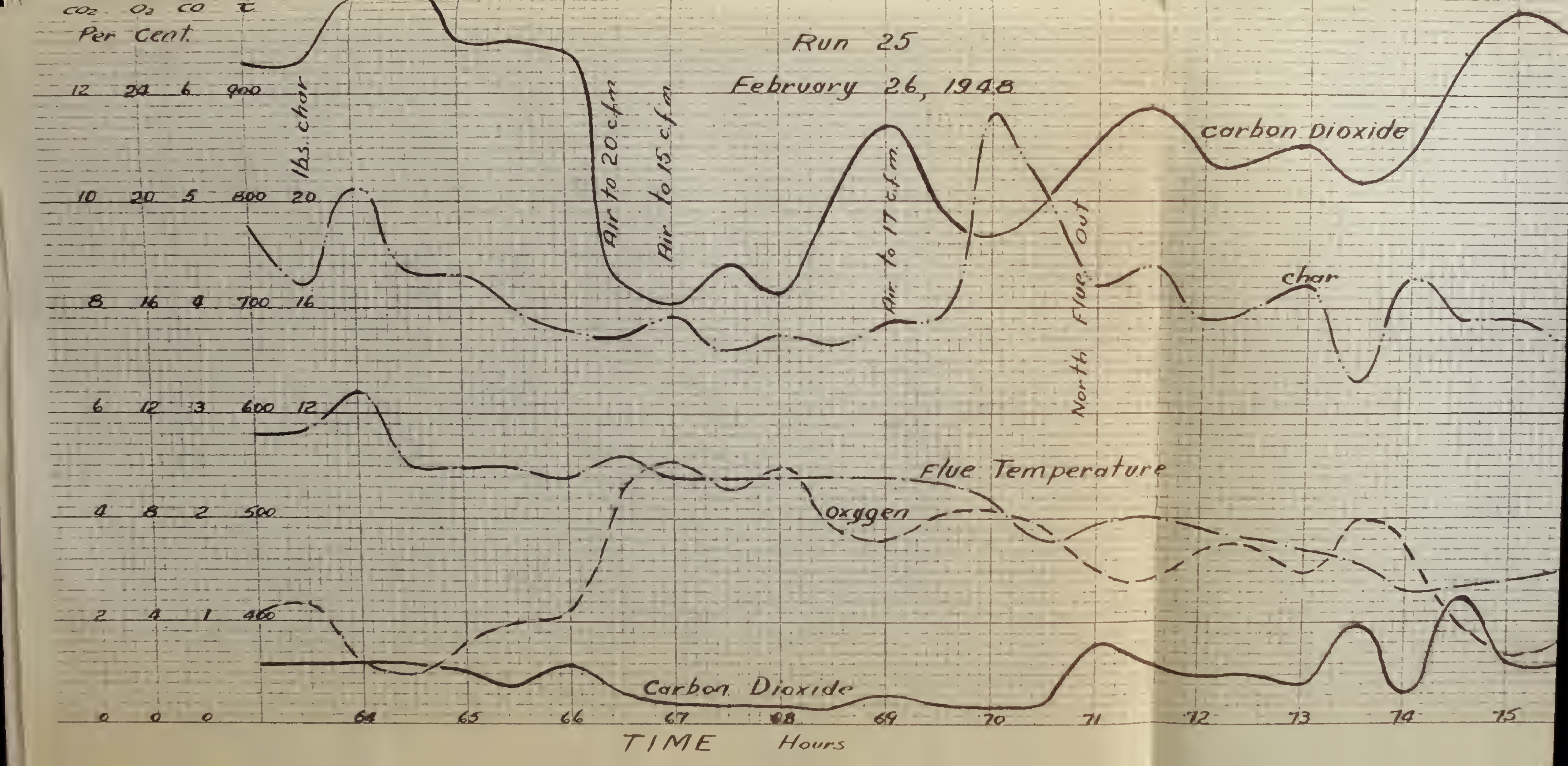

Carbon Dioxide
Run 25 February 24, 1948
char
Flue Temperature
Carbon Monoxide
Oxygen
28
29
30
31
32
33
34
35
36
37
38
39
Hours



Per Cent
CO2 O2 CO °C
Carbon Dioxide
1 lb. char
Sample 609-48 taken
Air at 11 c.f.m.
char
Char Sample 610-48 taken
Air at 13 c.f.m.
Flue Temper
Run 25
February 25, 1948
Carbon Monoxide
oxygen
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54



Dioxide
Char Sample 610-48 taken
Air at 13 c.f.m.
Air at 15 c.f.m.
char
Flue Temperature
25
February 25, 1948
noxide
51
52
53
54
55
56
57
58
59
60
61
62
63



CO_2 O_2 CO °F
Per Cent
Run 25
February 26, 1948
12 24 6 900
10 20 5 800 20
8 16 4 700 16
6 12 3 600 12
4 8 2 500
2 4 1 400
0 0 0
lbs. char
Air to 20 c.f.m
Air to 15 c.f.m
Air to 17 c.f.m.
North Flue Out
Carbon Dioxide
char
Flue Temperature
Oxygen
Carbon Dioxide
64 65 66 67 68 69 70 71 72 73 74 75
TIME Hours

The run can be divided into periods as shown in Table XLVIII.

TABLE XLVIII

Period	Air Rate c.f.m.	Time Hours	Average Carbon Dioxide Per cent.	Average Flue Temperature °Centigrade	Ave. Discharge lbs. per ½ Hr.	Ave. CO Per Cent.	Remarks
1	20	2	falling to 9	880°C.		0.5	starting up period
2	15	9	5 hours above 12% then 8 to 10%	fell 880° C. to 600° C.		0.5	stabilizing period to regulate excess CO2
3	11	2	rising to 12 then falling to 10	600		0.4	
4	9	26	12 for 7 hrs. then up to 15	slow decline 600 to 500	14.8	0.8	period of settling down to steady conditions
5	11	12	14	climbed back to and remained at 600	15.2	0.8	Excess air increased in steps over this period
6	13	6	13	600	17.4	0.6	
7	15	6	13	fell slowly from 600 to 540	17.2	0.5	
8	20	½	down to 8	550	15	0.2	Rate of excess air supply too great
9	15	2	11	540	15	0.2	short period of adjustment
10	17	7	11 to 13	fell slowly 540 to 350 one flue out	16.8	0.5	Final period before shut down.

The analyses of the four samples of char obtained are given in the following table.

TABLE XLIX

Air c.f.m.	Sample No.	Ash per cent.	Volatile per cent.	Calorific Value B.t.u. per lb.
9	609-48	21.5	10.0	11,370
11	610-48	21.6	9.8	11,350
15	611-48	21.0	12.6	11,420
17	612-48	20.4	14.0	11,330

The following observations can be drawn from the results of this run:

1. Provided close control is maintained so that the quantity of excess air used is not excessive the plant can be operated quite satisfactorily for long periods. In this run the total period was approximately 76 hours, at the end of which time the plant was shut down purposely.
2. Although no actual mechanical difficulties occurred with the discharge mechanism, it will be seen from Figure LVI that the actual discharge rate was variable and that, with the exception of a period of about two hours when a very marked variation occurred, the average variation was about four pounds per hour, equivalent to an average variation of approximately ten per cent. of the coal throughput. Although it is not possible from Figure LVI to correlate the variations in the discharge rate with the variations in the carbon dioxide content in the flue gases, presumably with a constant air supply the variation of the discharge rate is the

principle reason for the variation in the carbon dioxide content. The variations in the discharge rate indicate that if the plant should be designed on a larger scale considerable attention should be paid to the design of a discharge mechanism which would give smoother operations.

3. The variation of the carbon dioxide content of the waste gases with a constant air supply averages approximately two per cent. except during the period when an excessive amount of air was used. The oxygen contents of the flue gases correlate satisfactorily with the carbon dioxide contents.

4. The carbon monoxide content of the flue gases varied between 0.2 and 0.8 per cent. In general, the carbon monoxide content decreased as the air supply increased, due principally to direct dilution and possibly, in part, to the greater availability of oxygen.

5. The relationship between the quantity of air supplied and the flue temperature is not sufficiently precise to allow of a conclusive correlation. Generally speaking, over a fairly long period of operation, the flue gas temperature tended to fall by about 100°C. but when the air was increased, the temperature increased rapidly by 100°C. and thereafter, with increasing air supply, the temperature fell slowly. In general, the flue gas temperatures throughout the run were approximately 600°C. At this average temperature, 70 per cent. excess air must not be exceeded if the plant is to continue satisfactorily in operation for any considerable time.

6. It will be noted that in the final period with the use of a large quantity of excess air, when the flame in one flue expired the carbon dioxide content of the combined gases from the two flues increased. This occurrence has been commented on previously. The increased carbon dioxide content is due probably to improved combustion conditions in the one flue in which active combustion is still maintained and to the evolution of the large quantities of carbon dioxide in the flue in which the flame has expired.
7. The calorific values for the four samples of char do not show sufficiently wide differences to allow any conclusion to be drawn from them, but differences in the volatile contents are probably of some significance. The samples may be considered to be representative of reasonably steady operating conditions on the plant with the air rates shown.

Reference to Figure IV shows that while variations in the calorific values of chars produced from coals of a similar type between 500°C. and 600°C. differed only by about 300 B.t.u. per lb., the volatile matter content varied between 8 and 14 per cent. These variations are of the order of those obtained with the above samples. In the above run the higher volatile matter content is obtained with the highest air supply and the explanation may lie in that with a higher rate of air supply, a lower calorific intensity and flame temperature is obtained and the temperature of carbonization decreased accordingly. In short, the data in Table XLIX are of the order which might be anticipated.

It should be pointed out that with an air rate of

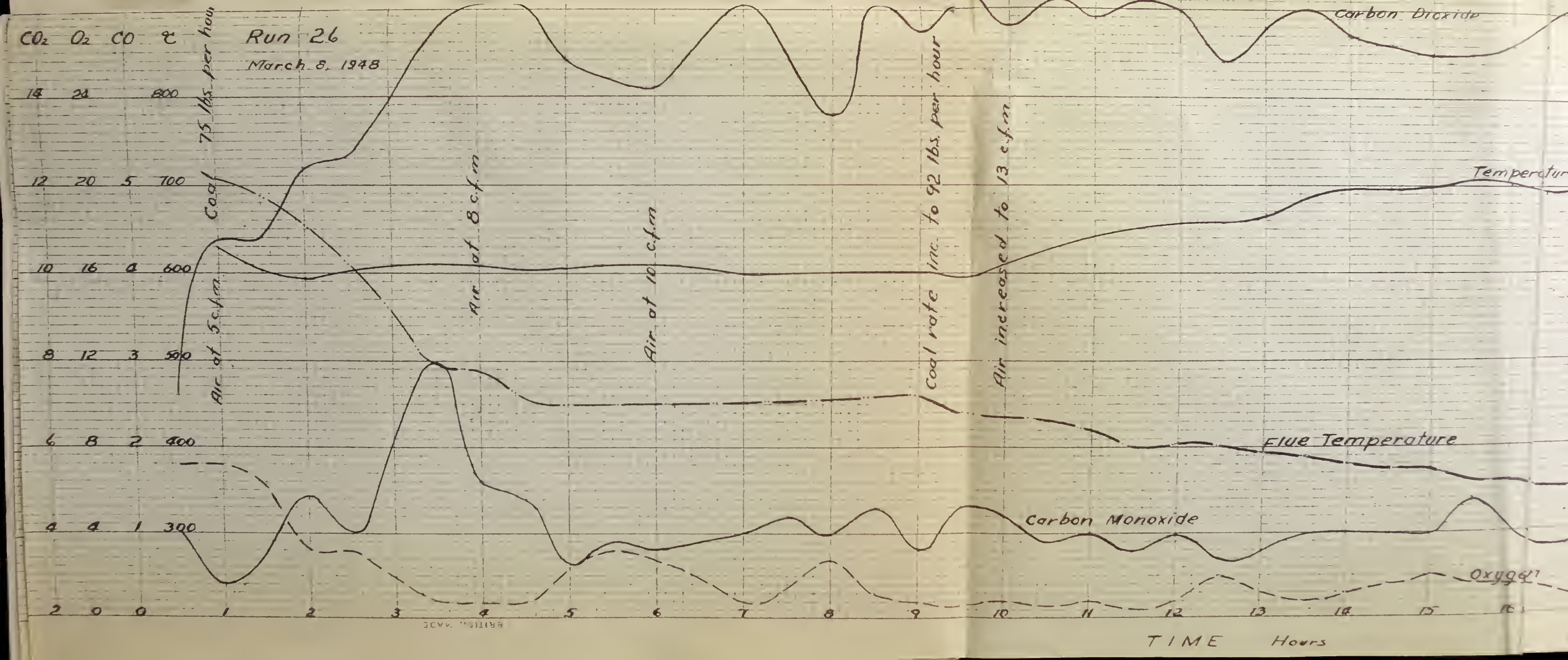
17 c.f.m. the plant did not operate for any substantial length of time but that at 15 c.f.m. operation was possible so that under these conditions of plant operation the limiting percentage of the volatile matter in the char would appear to be about 13 per cent. Whether this is the limiting volatile matter of the char which can be produced with this plant could not be determined until a further long period run was carried out with varying rates of discharge of char.

(b) To determine the maximum throughput of the retort a second long run was made in which the throughput was successively increased with a corresponding increase in air supply such as to maintain the desired carbon dioxide content in the waste gases. The results obtained in this run are shown in Figure LVII.

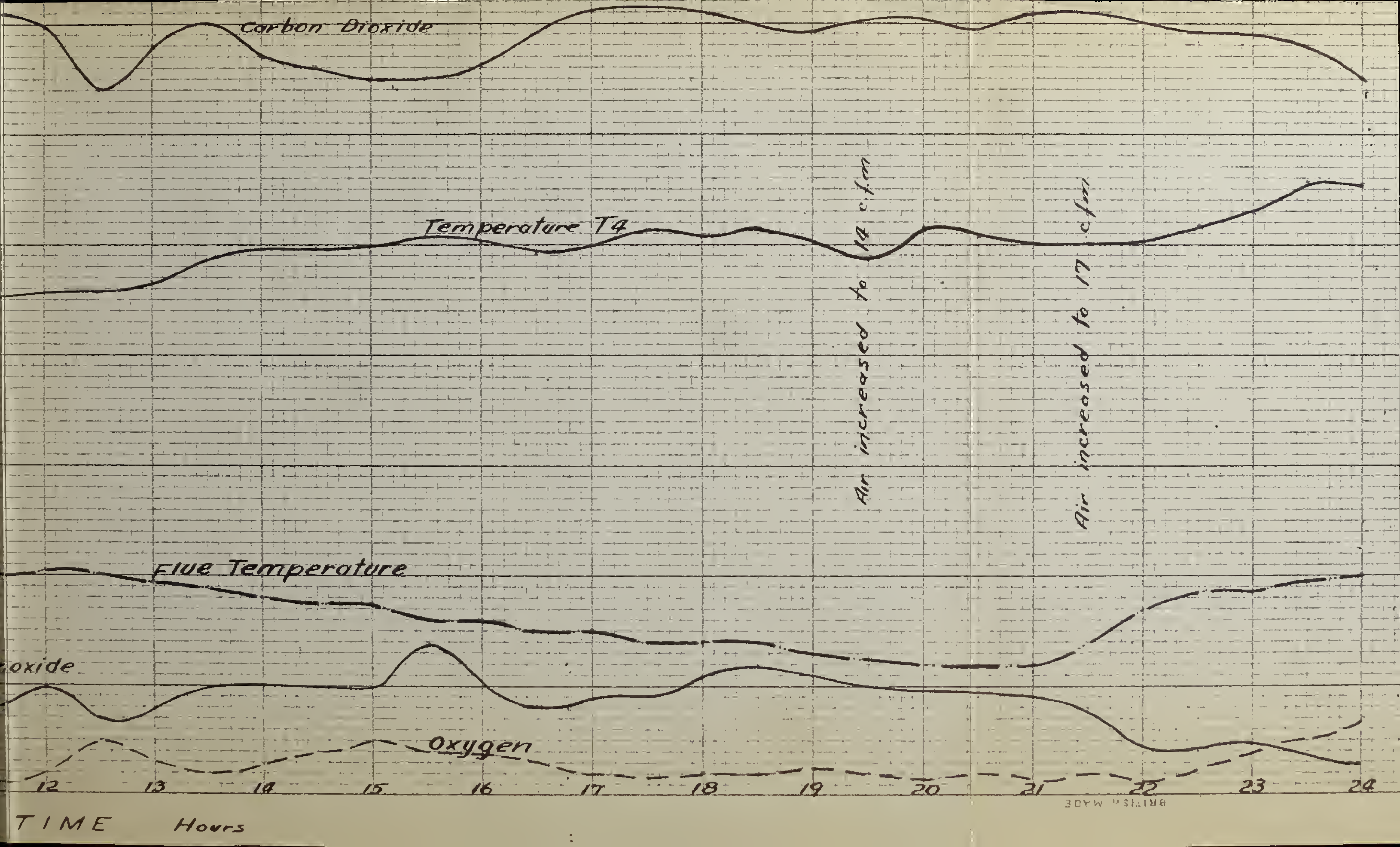
Initially, the plant was started up at the same rate as in run 25, i.e. at about 75 lbs. coal per hour. However, in this run the initial heating of the retort with natural gas was to a much lesser extent and some four hours had elapsed before operations became normal, i.e. until the carbon dioxide content in the flue gases had risen to the order of 15 per cent. or in excess of that amount.

After a total period of operation of approximately 9 hours, the coal rate was increased from 75 to 92 lbs. per hour. This rate was continued for 10 hours. It should be noted that the flue gas temperature fell over the whole of this period and that the temperature as measured by T.C. 4 increased by about 100°C. indicating the falling of the zone of highest temperatures in the coal stream.

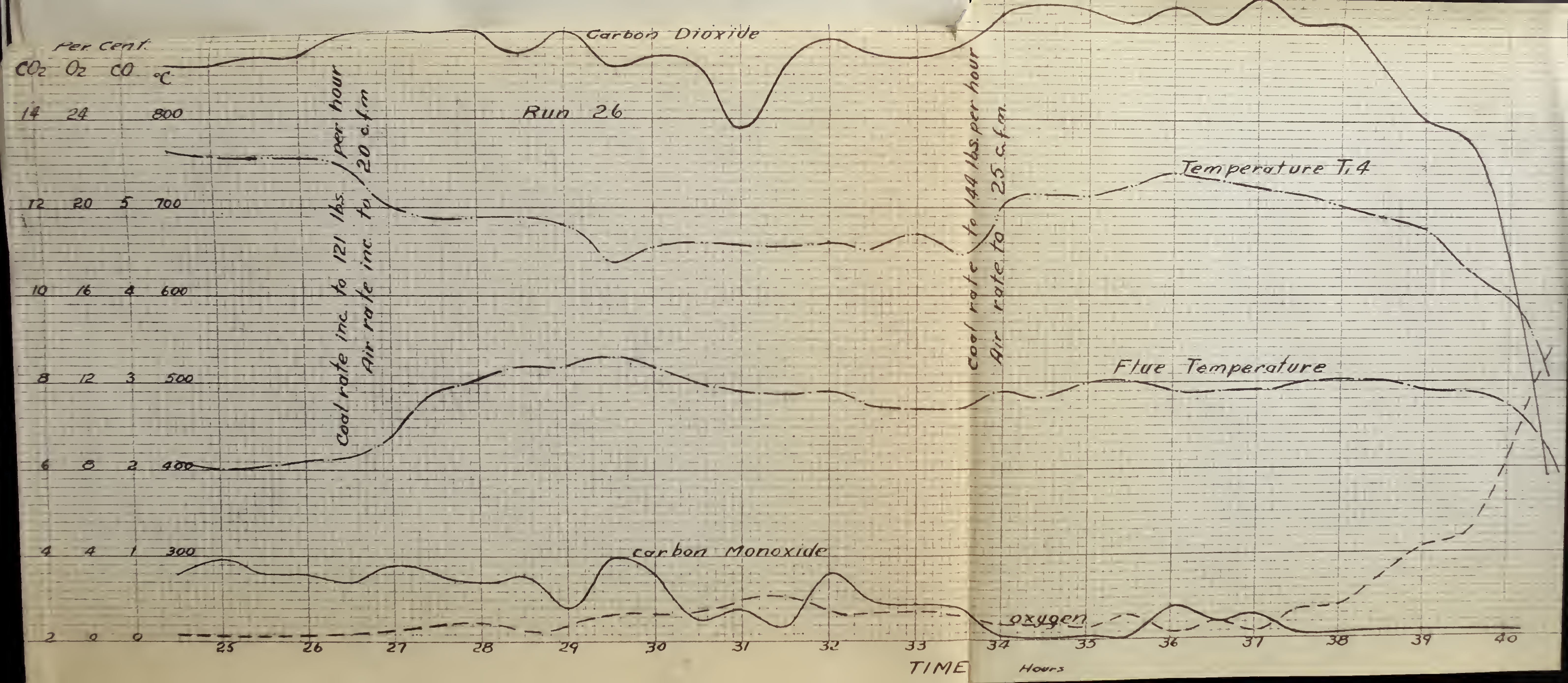
FIGURE LVII



CO2 O2 CO t
Run 26
March 8, 1948
Coal 75 lbs. per hour
Air at 5 c.f.m.
Air at 8 c.f.m
Air at 10 c.f.m
Coal rate inc. to 92 lbs. per hour
Air increased to 13 c.f.m
Carbon Dioxide
Temperature
Flue Temperature
Carbon Monoxide
Oxygen
TIME Hours



Carbon Dioxide
Temperature T4
Air increased to 14 c.f.m
Air increased to 17 c.f.m
Flue Temperature
oxide
Oxygen
12
13
14
15
16
17
18
19
20
21
22
23
24
TIME Hours



Per Cent
CO_2 O_2 CO °C
14 24 800
12 20 5 700
10 16 4 600
8 12 3 500
6 8 2 400
4 4 1 300
2 0 0
Carbon Dioxide
Run 26
Coal rate inc. to 121 lbs. per hour
Air rate inc. to 20 c.f.m.
Coal rate to 144 lbs. per hour
Air rate to 25 c.f.m.
Temperature T, 4
Flue Temperature
Carbon Monoxide
Oxygen
25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
TIME Hours

Over this period the carbon dioxide contents of the flue gases had risen at times to over 15 per cent, the oxygen content had fallen to as low as one half of one per cent. and the carbon monoxide content averaged approximately one per cent. It being considered that a careful increase in the excess air might reduce the carbon monoxide content of the waste gases, the air supplied was stepped up on two separate occasions. These increases in excess air resulted in a fall in the carbon monoxide content in the first stage but later the carbon monoxide again increased in amount to about one per cent. With the second increase in air supply the temperature at T.C. 4 increased by approximately 60°C. and the flue temperatures which had fallen steadily throughout the run to 320°C. at this point rose to 400°C.

During the next period of seven hours the retort was operated at an increased rate of 121 lbs. coal per hour, the air during this time being correspondingly increased. The flue gas temperatures rose fairly rapidly a further 100°C. to approximately 500°C. and this temperature was maintained to the end of the test some 14 hours later. Apart from variations in the carbon dioxide content in the gas of about two per cent. and variations in the carbon monoxide content from one to as low as 0.2 per cent., flue gas conditions over the next seven hours remained approximately the same but the temperature at T.C. 4 fell by about 100°C., the lower temperature being attained after about three hours and thereafter remaining constant. Finally, in the last stage of the test with a coal rate of 144 lbs. coal per hour,

[illegible]

[illegible]

i.e. almost double that at the initial stages and of course with a corresponding increase in air supply, the plant operated for approximately five hours at the end of which time the flames expired in both flues and the plant was shut down.

The shut down of the plant was very rapid. Over the last two hours of the test the carbon dioxide content of the flue gases fell very quickly, although the flue gas temperature was maintained to within about 1/2 hour of the shut down of the plant, whilst the temperature at T.C. 4 fell rapidly over the last 1 1/2 hours. The low carbon monoxide figure over this period appears to be due to dilution.

Prior to any changes of throughput samples of the char discharged were taken over a period of one hour of operation. The results of the analyses of these samples are shown in Table L.

The operation of the retort is dependent on a number of factors such as the rate of throughput, the rate of air supply, and the temperature of distillation of the coal which last factor in conjunction with the rate of air supply, determines the composition of the flue gases and also their volume and temperature. These in turn determine the quantity of heat transferred to the coal stream. It is possible to interpret the results which have been obtained in relation to Figure IV which shows the results of the earlier work of the Mines Branch in Ottawa (6) obtained by the carbonization of Black Diamond Coal under laboratory conditions. From this figure data have been calculated which show the variation of the volatile matter and calorific value of the char over the temperature range from 350°C. to 700°C., on the dry ash-free basis. The data are given in Table LI

TABLE L

Proximate Analyses and Calorific Values of Char
Produced in Run 26

Sample No.	A	B	C	D
Throughput lbs. coal per hour	75	92	121	144
Air Rate c.f.m.	10	15	20	25
Yield, Per cent. by weight of coal	56	50	54	53
Composition of Char as Produced				
Volatile Matter, Per cent.	10.3	8.3	14.5	21.1
Ash, Per cent.	23.3	21.2	19.5	16.9
Fixed Carbon, Per cent.	66.4	70.5	66.0	62.0
	100.0	100.0	100.0	100.0
Calorific Value, Gross, B.t.u. per lb.	11,170	11,530	11,420	11,340
Composition of Char Dry Ash-Free Basis				
Volatile Matter, Per cent.	13.4	10.5	18.0	25.2
Fixed Carbon, Per cent.	86.6	89.5	82.0	74.8
	100.0	100.0	100.0	100.0
Calorific Value, gross, B.t.u. per lb.	14,580	14,630	14,180	13,650

and expressed graphically in Figure LVIII.

TABLE LI

Proximate Analyses and Calorific Values of Char Produced From Black Diamond Coal at Various Temperatures of Carbonization (Mines Branch - Ottawa.)

Ash-Free Basis

	Temperatures °C.			
	350	400	450	500
Volatile Matter, Per cent.	33.2	25.7	20.0	15.7
Fixed Carbon, Per cent.	66.8	74.3	80.0	84.3
	100.0	100.0	100.0	100.0
Calorific Value, B.t.u. per lb.	12,940	13,800	14,280	14,680
	550	600	650	700
Volatile Matter, Per cent.	11.3	8.9	6.0	4.0
Fixed Carbon, Per cent.	88.7	91.1	94.0	96.0
	100.0	100.0	100.0	100.0
Calorific Value, B.t.u. per lb.	15,120	15,290	15,280	15,120

Making allowances for differences in the methods of carbonization in the two cases and for possible variations in the samples of coal used, it is considered that the results obtained in Run 26 can be compared with those shown in Table LI. When the volatile matter contents and calorific values on a dry, ash-free basis in Table L are related to the curves in Figure LVIII they take up the positions shown respectively at

[illegible]

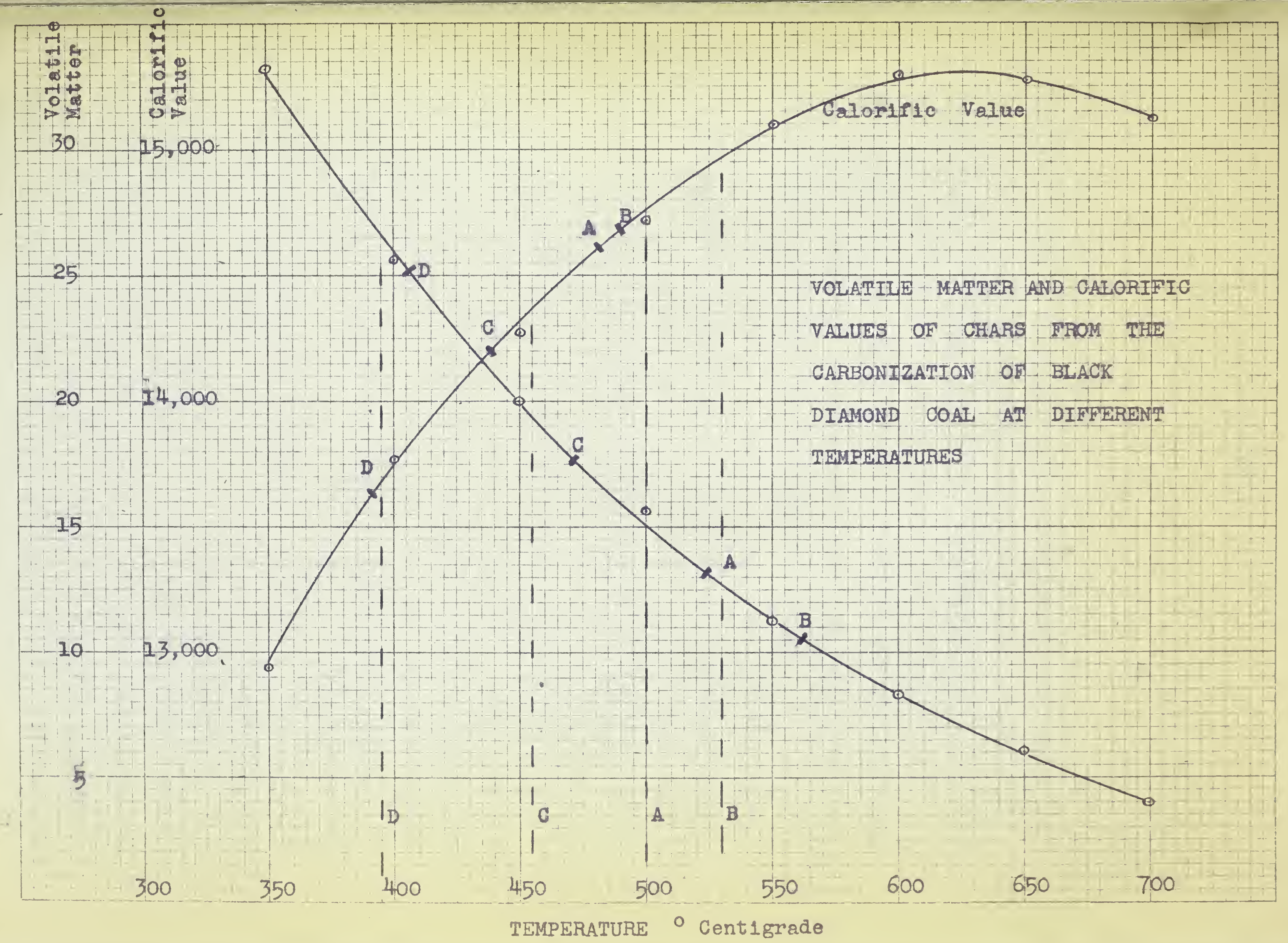
[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

FIGURE LVIII



Volatile Matter
Calorific Value
30
25
20
15
10
5
15,000
14,000
13,000
Calorific Value
VOLATILE MATTER AND CALORIFIC VALUES OF CHARS FROM THE CARBONIZATION OF BLACK DIAMOND COAL AT DIFFERENT TEMPERATURES
A
B
C
D
300
350
400
450
500
550
600
650
700
TEMPERATURE ° Centigrade

A, B, C, D, these letters corresponding to the sample numbers in Table L . It will be seen that the order of the positions on the two curves is the same. If, with respect to a particular section of Run 26 a mean line be drawn between the position on the volatile matter curve and the position on the calorific value curve, perpendicular to the temperature axis, this gives an approximation to the mean temperature of carbonization to which the coal over this period of the run has been subjected. It will be seen that for samples A, B, C, D, these temperatures are respectively 500, 530, 455 and 395°C.

It should be recognized that these are simply representative temperatures and not the actual temperatures. That these are simply representative is substantiated by an examination of the actual curves obtained in Run 26 as shown on Figure LVII for it will be seen that with a coal throughput of 92 lbs. per hour and with the lowest excess air quantity, the flue gas temperatures were approaching 300°C. but at higher rates of air supply the temperatures approached 400°C. When, however, the coal rate was increased to 120 lbs. per hour the temperature rose to 500°C. and despite the high carbon dioxide content in the flue gases, the heat losses in these gases must have been substantially increased.

The latter state of affairs is represented by position B in Figure LVIII; the coal was presumably subjected to a carbonization temperature of 530°C. In the earlier period, represented by position A, larger quantities of heat were lost in the flue gases and conceivably this is coincident with the treatment which, in Figure LVIII, was represented at A by a temperature of 500°C.

[illegible]

When the rate of throughput was increased to 121 lbs. of coal per hour, it will be seen that the curves in Figure LVIII, representing the volatile matter content and calorific values in the char produced, become steeper, i.e. for equal temperature differences there is an increase in the rate at which the volatile matter content increases and the calorific values of the char produced falls. Eventually, when the coal rate was increased to 144 lbs. per hour as represented by position D in Figure LVIII, the quantity and quality of the volatile matter distilled from the coal was reduced to such a degree that continued operation of the process was impossible.

In the actual operation of the plant, a carbon dioxide content in the flue gases in excess of about fifteen per cent. may be obtained when the coal is carbonized at the lower temperatures. At these temperatures the relative proportions of carbon dioxide derived from the combustion of the volatile material and the carbon dioxide derived as such from the distillation of the coal are altered and the ratio of these two quantities decreases.

This may be explained in a rather different way by saying that under conditions in which the throughput begins to exceed 92 lbs. of coal per hour, the length of the zone over which gases containing large volumes of carbon dioxide are produced, is increased and consequently with a diminishing amount of available heat, the heat transferred to the charge is reduced accordingly, resulting in a higher heat loss in the waste gases. Presumably a time is reached when the zone, from

which gases containing large quantities of carbon dioxide are evolved, is so extensive that combustion of the gas even under the best conditions of air supply becomes impossible because the limit of inflammability is exceeded.

The addition of inert gases to combustible gases materially alters the limits of inflammability (19), the curves for the limits of inflammability with varying percentages of combustible gases in the mixtures being thrown towards the higher limit, i.e. larger quantities of combustible gases are required for the mixtures to be inflammable when considerable quantities of non combustible gases are present. In simplest terms the effect is to blanket the flame and extinguish it.

Considering the results of this run as a whole one must conclude that the maximum throughput of the run is about 92 lbs. of coal per hour. Generalizing, the maximum throughput of the plant is in the region of 100 lbs. of coal per hour but this throughput would be obtained only by a careful control of operating conditions.

VI. CONCLUSIONS

1. The pilot-plant-scale, low-temperature carbonization retort described in this thesis will operate continuously for considerable periods of time to produce from a low-rank subbituminous coal (Black Diamond, Edmonton), yields of char from approximately 50 to 56 per cent. by weight of the coal carbonized, containing approximately 8 to 10 per cent. of volatile matter respectively.

2. For continuous operation as low an excess air quantity for combustion of the volatile matter as possible should be employed. It has been shown that quantities of excess air of the order of less than five per cent., which quantity corresponds to fifteen per cent. carbon dioxide in the flue gases, gives good operating conditions. With a very wide range of excess air quantities the amount of undeveloped heat due to carbon monoxide surviving in the flue gases does not vary greatly. The carbon monoxide content throughout is of the order of one-half to one per cent. It is not clear as to the zone from which this carbon monoxide arises. If the carbon monoxide survives from the early stages of carbonization, in the upper regions of the carbonizer, its survival can well be understood.

3. For further development of this system of carbonization, the satisfactory utilization of the waste heat is a matter of importance. This waste heat could be utilized for providing natural draft thus probably dispensing with

existing forced and induced draft fans. An alternative would be its use for preheating air for combustion purposes, but the effect of preheating the air on the throughput of the plant and upon the nature of the product requires further investigation. The heat in the waste gases might alternatively be utilized for predrying the coal prior to its passage to the carbonizer. The utilization of the waste heat for the predrying of the coal would presumably have a marked effect upon operating conditions. For reasons which are not understood in the one run in which considerably less moisture was present in the coal, the flue temperatures were lower than when coal of normal moisture content was employed. These methods of waste heat utilization are subjects suitable for further investigation.

4. The throughput of the plant is related to the quality of the char. Under good operating conditions the plant will carbonize approximately 21 1/2 hundredweights per 24 hour day. Development of this system of carbonization to a point at which industrial operation might be considered, depends obviously not simply on a multiplication of a unit of present dimensions, but on the redesigning of this unit, in such a way as to provide the basic constructional data for a plant to work on the industrial scale. Initially, the question of suitable materials of construction would have to be determined and thereafter it is conceivable that the throughput of the carbonizer would be increased perhaps by designing a battery broadly on the lines of a conventional modern by-product coke oven.

5. With regard to the specific constructional features of the pilot plant:

(a) Over the whole of the experimental period described, the carborundum baffles and end plates have showed very little wear and have proved entirely satisfactory. This does not apply to the end plates made of "Plicast" which periodically gave rise to trouble owing to breakage.

(b) In any new design arrangements should be made for continuous feed of coal to the charging hopper.

(c) The existing discharge mechanism operates at a rather variable rate and in any new design efforts should be made to design a discharge mechanism which would give more regular working.

(d) The cooling system might also receive attention since occasionally difficulty has been met in cooling the charge sufficiently to prevent the char firing upon discharge.

6. In the matter of the redesigning of the plant, experiments should be made previously on the flow of material in a baffle system of the type employed and of the influence of the fineness of division of coal on such flow. Experiments of a relatively simple nature could be designed to determine the maximum allowable distance for free flow of material of varying size.

7. On the several occasions when wet coal was inadvertently introduced into the retort, free flow of the coal was impeded and operation of the retort ceased. Even an amount of superficial water of only two per cent. was found to cause choking of the plant. This is one of the severe limitations

on this type of retort. It is, however, a limitation which might not be met if waste heat could be utilized for pre-drying.

VII. Comparision of Performance of the Research Council Experimental Plant with that of the Lurgi Plant at Bienfait

Finally, it has been thought desirable to make some broad comparison between the results of the R.C.A. experiments and the results obtained on the established Lurgi process which is in operation in Southern Saskatchewan for a like purpose.

Full details of the Bienfait plant are not available, but it is understood the Lurgi plant will not operate satisfactorily with material less than one quarter inch mesh size. This can readily be understood since in the Lurgi there is a large and deep bed of material undergoing treatment and the satisfactory operation depends on the free passage of gas through such a bed, as in the case of a producer or to a lesser extent a boiler fire bed. The R.C.A. experimental plant is not subject to the same limitations and will carbonize satisfactorily material containing approximately 50 per cent. by weight below one quarter inch mesh size. The limiting percentage of specific particle size with the R.C.A. plant has not been determined, but that material containing so large a proportion of fine coal can be treated is a marked advantage as compared with a Lurgi carbonizer.

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[illegible]

[illegible]

[illegible]

[illegible]

It should be pointed out, however, that the present R.C.A. retort will obviously not treat pieces of coal of a size greater than the free distance between two successive baffles. Throughout the experimental work, although the coal had been screened at the mine to minus 3/4 inch mesh size, it was found necessary to rescreen it since it contained a few large pieces which could cause a blockage of the baffle system. In any large scale plant it would be essential to install and carefully operate a plant for screening the coal prior to its carbonization.

At this stage, any comparison of the cost of manufacturing briquettes from a char from the type of subbituminous coal used in the experimental retort with the cost of manufacture in the Lurgi process is previous, but an estimate may be of interest of the price at which coal would have to be purchased for use in the Lurgi system to make that system as economical as the R.C.A. plant.

The following assumptions are made:

1. That coal which can be treated by the R.C.A. plant at the present time is almost a waste product at the subbituminous mines in Alberta. A reliable estimate of the value of this material is $1.25 per ton. Coal of the size which can be treated by the Lurgi plant, i.e. between 1/4 inch and 4 inches could presumably be costed at a higher figure.

2. The yield of char on the Lurgi plant is 48 per cent. as compared with the 50 per cent. yield with the R.C.A. plant.

3. In the Lurgi plant a yield of 5.8 gallons of tar per ton of coal is recovered and if the tar has a specific gravity of

one, the weight of tar per ton of lignite is 58 lbs. This 58 lbs. of tar on distillation may be considered to yield 23.2 lbs. pitch and 4.0 gallons of tar acids. It is assumed that there is no surplus gas in the process.

4. In briquetting, it is assumed that the same quantity of binder, this amount being 10 per cent., would be required for the chars from both the Lurgi and R.C.A. plants. Asphalt binder would be used entirely in the R.C.A. plant but in the Lurgi plant it would be reduced by the amount of pitch recovered from the carbonization process. The cost of asphalt binder is taken as $30.00 per ton.

5. The briquettes from both the Lurgi and R.C.A. plants would command the same market price, say $10.00 per ton.

The positions of the two plants can be summarized as follows:

Per Ton of Coal as Carbonized

Receipts				
	Lurgi		R.C.A.	
Char	0.48 Tons		0.50 Tons	
Binder	0.048 Tons		0.050 Tons	
	0.528 Tons at $10.00/ton	$5.28	0.550 Tons at $10.00/ton	$5.50
Tar Acids	4.0 gals. at $0.10/gal.	0.40		--
		$5.68		$5.50

Per Ton of Coal as Carbonized

Expenditures

At this stage, the price of coal of suitable size for carbonization in a Lurgi plant being unknown will be taken as "x".

	Lurgi			R.C.A.	
Coal			\$ x		\$1.25
Asphalt	Binder used	0.048		0.050 tons	
	Pitch recovered	0.00116		---	
	Asphalt purchased	0.0364		0.050 tons	
	at \$30.00/ton		\$1.09		\$1.50
	Total		\$x + \$1.09		\$2.75

The income from the Lurgi plant exceeds the income from the R.C.A. plant by \$0.18. Therefore, if the two plants are compared on this basis

$x + 1.092 - 0.18 = 2.75$ and $x = 1.84$

i.e. for the Lurgi plant to operate as advantageously as the R.C.A. plant the price of the much larger size coal that is used by that plant must not exceed \$1.84 per ton.

This conclusion is, of course, a very simplified statement which takes no account of capital expenditures, interest and running costs. It is presented simply as indicating that the R.C.A. plant offers some possibilities, provided a design can be evolved which will allow of operations on a large scale as advantageously as is indicated by the experimental work described in this thesis.

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